1985

Estuarine Quality

US Enivironmental Protection Agency

URBAN RUNOFF POLLUTANT INPUTS TO NARRAGANSETT BAY: COMPARISON TO POINT SOURCES

EVA J. HOFFMAN
State Coordinator
Narragansett Bay Project
Rhode Island Department of Environmental Management
Providence, Rhode Island

ABSTRACT

Urban runoff samples were collected from four drains, each serving a different land use: residential, commercial, highway, and industrial. Twenty-one storm events were monitored to establish mass discharge rates of water volume, suspended solids, petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and a variety of trace metals, as a function of storm rainfall and land use. These loading rates were combined with local rainfall and land use records to estimate annual urban runoff inputs to the Narragansett Bay watershed. For comparison, we compiled a point source inventory for the same components though self-monitoring reports and past monitoring studies conducted at the university, augmented with additional analyses as required. Urban runoff was found to be the source of 48 percent of the petroleum hydrocarbons, 3 percent of the lower molecular weight (2 ring) polycyclic aromatic hydrocarbons, 44 percent of the higher molecular weight polycyclic aromatic hydrocarbons, 65 percent of the lead, 56 percent of the zinc, and 5 percent of the copper entering the Narragansett Bay watershed annually. The application of the urban runoff loading rates was tested on one of the Narragansett Bay tributaries, the Pawtuxet River. The wet-weather related mass discharge rates for these constituents in the river, as monitored during and following one storm event, was estimated within a factor of 2 using our loading factors with the rainfall and local land use data. The fate and transport of wet-weather components in the Narragansett Bay estuary will be examined as part of the Narragansett Bay Project of the EPA National Estuaries Program.

Narragansett Bay is one of the best studied estuaries in the world. The University of Rhode Island's Graduate School of Oceanography, Brown University, Roger Williams College, and neighboring institutions such as the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution have used the bay as a research laboratory. In 1979, Rhode Island's Coastal Resources Center published The Bay Bib, containing over 1,800 references to literature on this estuary. The Center then made an attempt to examine these data in order to answer the question, "Where do the various pollutants in Narragansett Bay come from?" One conclusion of this study states simply that "Sufficient data do not exist to assess the relative importance of the many sources of pollution in the upper bay's watershed. Data comparable to that available on effluents from sewage treatment plants and industrial sources do not exist for flows resulting from runoff and other nonpoint sources" (Olsen and Lee, 1979).

URBAN RUNOFF

As a first step in evaluating the annual pollutant loads generated by urban runoff, it is necessary to have loading rates (such as mass/drainage area/time) that can be applied with some degree of confidence to the drainage area in question. Although appropriate urban runoff loading factors exist for metals generated by the National Urban Runoff Program (NURP) (U.S. Environ. Prot. Agency, 1984), the urban runoff data on hydrocarbons and PAHs were minimal. Because we were particularly interested in these organic components, we found it necessary to conduct an urban runoff study of our own (for more detail see Hoffman et al. 1983a, 1982, 1985, 1984, 1983b). The experiment was designed to examine hydrocarbons and PAHs in runoff as a function of land use in a manner similarly used for other components in the NURP studies. The results of our study, derived from 21 storm events for organics, and 12 storm events for metals, are given in

Table 1. Where they are available, runoff loading factors generated by the NURP studies are included for comparison.

Inspection of our data reveal a strong dependence of urban runoff pollutant loading with land use. Often differences by several orders of magnitude are involved. The urban runoff loadings for PAHs with three or more rings Fe, Mn, Cu, Pb, Cd, Zn, and suspended solids (TSS) were highest at the interstate highway location. Even though highways represent only a very small proportion of the land use in some locations, they become more important near urban areas. Since the loading factors are high, the highway land use can become an important part of the total urban runoff loads to urban water bodies. Highways were not studied separately in the NURP program.

Loadings for petroleum hydrocarbons and PAHs with two rings were highest at the industrial location. Our collection site, admittedly, could be termed "heavy industrial," since it was located in the Port of Providence area. These values, then, would not be typical of newly developed industrial parks, which would have loadings similar to our commercial location. (The commercial land use and industrial land use were combined in the NURP studies in 1984 which, in our view, would be satisfactory for light industry, but inappropriate for heavy industrial areas as illustrated in Table 1.)

The next step is the combination of the urban runoff loading factors with land use data for the specific drainage basin of interest. This would seem, at first inspection, to be a trivial matter, but hidden pitfalls exist for the unwary scientist. To give only two examples: (1) poor choice of land-use categories (categories for urban planning purposes may not be the best for urban runoff studies because the utility category can include both power line right-of-ways (open land) and power plants (heavy industry)); (2) land uses as a function of drainage basin are most frequently derived using topographical maps which may not represent where the storm sewers actually carry the water.

Once we had determined loading factors and found land use statistics, we could then calculate urban runoff loads to the waterbody of interest, for areas which are newly developed. However, the situation in Providence, and in other cities of the Northeast where sewer systems collect both wastewater and urban runoff, leads to complications in the calculations. In the 1890s, at the time of its original construction, the combined system in Providence was considered innovative because it collected urban runoff, recognized even then as contributing to water pollution. At that time the runoff did not contain automotive-related pollutants, but horse-related ones. A schematic of a typical combined sewer system is given in Figure 1.

In these systems, urban runoff can take any of three routes: it can travel down the street to the nearest waterbody via overland transport; it can travel to a catch basin tied into a separate storm sewer which usually takes the runoff to the nearest waterbody; or it can travel to a catch basin tied into a combined sewer system. Once in a combined system, it can travel to a sewage treatment plant, which may not be in the same drainage basin, or can overflow the system via a combined sewer overflow, usually in the drainage basin of origin.

As a first step, it is necessary to subdivide the land use statistics into subdrainage areas, so that loading rates for the areas served by storm drains can be calculated independent of areas served by combined sewers. For Providence, this was done using a land use map superimposed on a city sewer map (Martin and Robadue, 1983). It is not difficult to estimate the amount going into combined sewers, once the land use characteristics for these areas are available. The more difficult question is where does the runoff go once it gets into the system? Does it overflow the system close to the source? Does it go all the way to and through the treatment plant? Does it go to the treatment plant only to be bypassed around the plant? Once the runoff goes into a combined system it is mixed with unknown proportions of raw sewage; how much of this sewage overflows along with the runoff during rain events?

There are two basic approaches to answering these questions. One can monitor each overflow individually or model the system. The city of Providence has been divided into nine combined sewer overflow (CSO) drainage districts. Preliminary design projects for two of these districts have been contracted and include flow monitoring of each CSO in these two districts and some pollutant determinations on selected CSOs. These two projects cost in excess of $1.2 million. Although we now have some conception of the nature of CSO discharge in two districts, the data are not useful in assessing the problems in the other seven districts of the city. The monitoring of each of the 65 overflows in Providence would be logistically difficult and very expensive. Modeling of the sewer system is a much less costly way to estimate how important CSOs are in context with other sources. It is also an inexpensive method of assessing whether expensive design and monitoring studies are warranted.

Three models have been attempted for Providence's combined sewer system: one model estimates CSOs by difference between total flows entering the system and the amount that gets all the way to the plant (Hoffman, 1983); two other models estimate CSOs by calculating the sewage and runoff flows in each district sending all of it to the plant until the capacity of the connector pipes in the dis-

Table 1.—Urban runoff loading factors as a function of land use.

Pollutant	Residential[1] (single family suburban)		Commercial[1] (shopping mall)		Industrial[1] (heavy)	Highway[1] (8 lane)
Petroleum hydrocarbons (HC)	180		580		14000	7800
LMW-PAHs	0.009		0.100		2.42	1.220
HMW-PAHs	0.258		0.589		3.97	16.9
Fe	135		166		856	915
Mn	49.6		8.6		65.8	513
Cu	3.0	(8)	3.0	(22)	35.3	146
Pb	22.4	(36)	43.6	(82)	166	2250
Cd	0.18		0.69		0.85	2.48
Zn	43.5	(34)	n.d.	(177)	639	7020
Suspended solids (TSS)	4400	(12200)	32400	(54300)	548000	424000

[1](kg/km² of land use/yr)
Annual rainfall = 121 cm/yr
n.d. not determined;
Values in parentheses are loading factors as projected from National Urban Runoff Program (NURP).

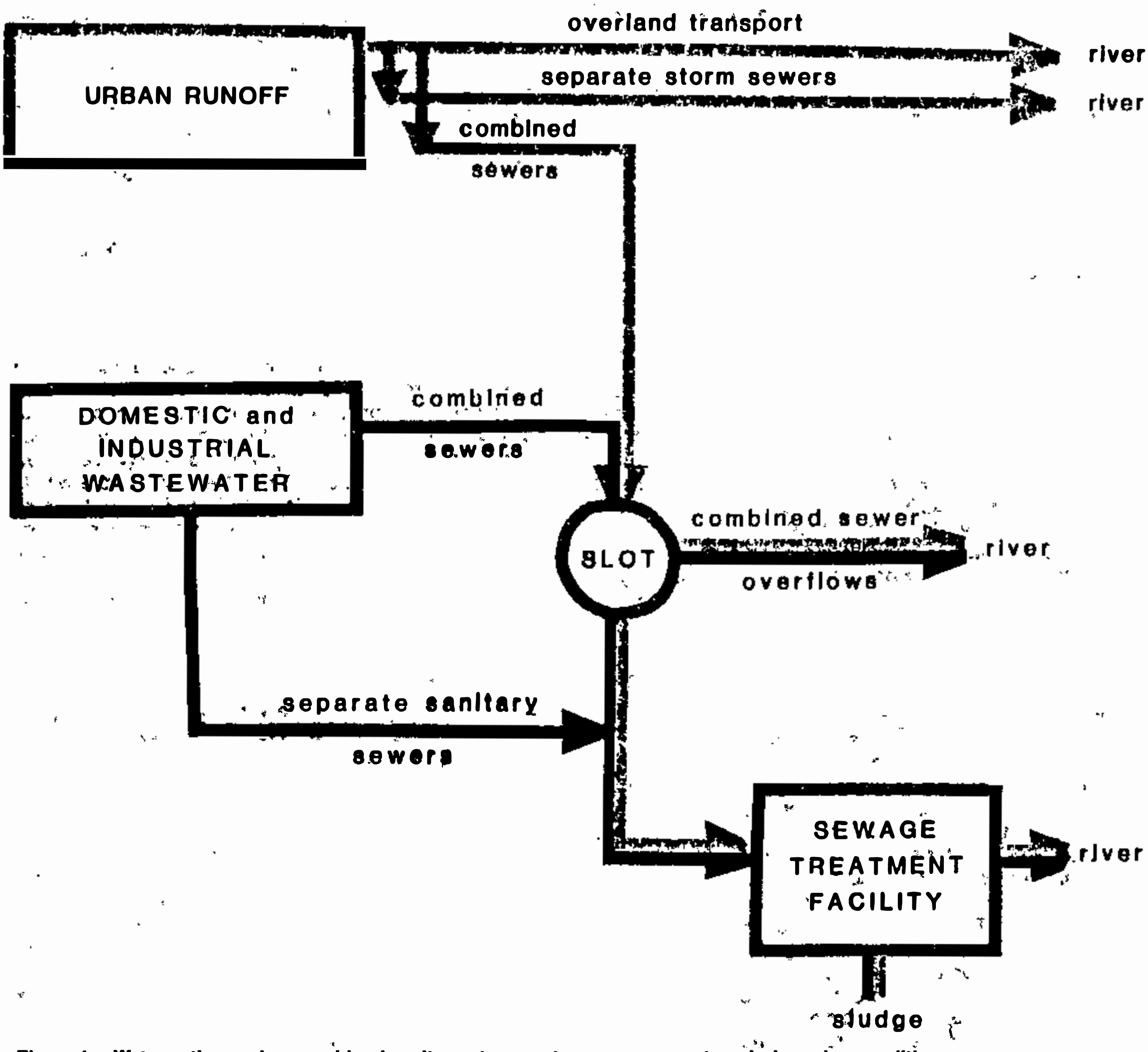

Figure 1.—Water pathways in a combined sanitary-storm water sewerage system during rainy conditions.

trict is reached, the rest being discharged by the local CSO (Martin and Robadue, 1983; Metcalf and Eddy, 1983).

All three of the system models predict that some fraction of the runoff goes to the treatment plant, although the absolute magnitude varies. We monitored the influent and the effluent of this plant during three rainstorms to evaluate the impact of urban runoff in the plant (Hoffman et al. 1985). Urban runoff was found to affect the plant in two ways: first by increasing the loads of pollutants during storms and then by producing elevated flow rates which are sometimes sufficient to produce hydraulic overloadings of the secondary treatment system. When combined, these produce higher mass discharges from the plant in wet weather than during analogous dry periods. It is likely that each treatment plant receiving stormwater discharges will behave differently in this aspect.

In summary, to produce urban runoff estimates for Narragansett Bay, we monitored storm drains serving different land uses; we modified land use data, when necessary, to make them useful for water quality planning; we estimated how much urban runoff never went to the drainage basin of origin but went to a treatment plant; and we estimated how much runoff mixed with sewage and was discharged by CSOs. For example, we calculated that, on an annual basis in Providence, 47 metric tons of hydrocarbons were discharged by separate storm drains, 20 metric tons were discharged via combined sewer overflows, 100 metric tons went to the treatment plant during rainy conditions, and 222 metric tons went to the treatment plant during dry conditions. Similarly, we calculated the urban runoff expected from each of the 36 cities and towns surrounding the bay. These total urban runoff Narragansett Bay watershed calculations for a variety of different pollutants are compared with other sources later.

WASTE CRANKCASE OIL DUMPING

The improper disposal of used crankcase oil down sewers has been cited by numerous authors as a potential contribution to the oil content of sewage and receiving waters. The impact of this disposal method is impossible to assess directly, since it is done surreptitiously. Often evidence is seen—empty oil cans in rivers and on streets, large oil blotches around catch basins—but the magnitude of the problem has been the subject only of speculation. To address this question, we designed a survey that we mailed to 1,000 Providence residents. Under the guise of asking whether they would participate in a used oil recycling program, we slipped in a question about their current dis-

Table 2.—Used crankcase oil disposal practices.

	Urban	Suburban	Rural
Population density	>3000/mi²	3000-500/mi².	<500/mi²
Percent of oil changed by owners	33.5%	39.9%	48.5%
Disposal method used by owners:		Percentage of oil volume	
Give it to service station	6.9	10.4	3.0
Put in garbage	40.7	23.4	14.0
Store at home	4.1	6.5	5.0
Pour it out or bury it in backyard	29.7	39.0	38.0
Pour it on the road	4.8	4.0	0
Pour it down sewer	7.6.	2.6	1.0
Take to dump	2.8	3.9	9.0
Other	3.5	14.3	24.0

posal practices (Hoffman et al. 1980). Following this study, the same questionnaire was used again in a South Carolina legislative study, querying South Carolinians about their habits in this regard (Marchand et al. 1980). These two data sets give us an idea of what urban, suburban, and rural residents do with their waste oil. A summary of the survey results is given in Table 2.

The joint study (Hoffman et al. 1981) found that: on the average, car owners changed their crankcase oil in their vehicles twice a year, regardless of population density; as the population density increased, the percentage of do-it-yourself oil changers decreased; the disposal methods used are a function of demographic parameters; and the specific practices of pouring the used oil on the road or pouring it down catch basins is clearly more common in highly urban areas where catch basins are convenient.

We used the survey results to predict waste oil contributions of each city and town in the Narragansett Bay drainage basin. First, we classified each town into one of three categories (urban, suburban, and rural) by population density criteria to determine which of the data sets were the most appropriate for each town. Then we calculated the amount of waste oil dumped down sewers or poured on roads per town, using the number of vehicle registrations in each town. The other waste oil disposal methods could also eventually result in surface or ground water contamination, but this process would take longer and some degradation is possible. Leaks from underground storage tanks used for waste oil in gas stations are also a potential water pollution problem. However, when oil is dumped down a sewer, its transportation to receiving waters is rapid. Our waste oil dumping estimates are based only on the amount dumped down sewers and represent a conservative value if other methods of oil disposal also contribute to water pollution.

Because used crankcase oil contains metals and PAHs, we estimated the loadings expected for these constituents using literature data about the composition of used crankcase oil (Pruell, 1983; Brinkman et al. 1981).

ASSEMBLY

A word of caution on assembly of the final pollutant inventory: The dangers of double accounting must be recognized. This is a particular hazard with combined systems (i.e., urban runoff going to a sewage treatment facility could be put in either the urban runoff category or the sewage category). For the purposes of these calculations, we have made the following assumptions: (a) urban runoff going to sewage treatment plants becomes part of the sewage values and is no longer part of the urban runoff category; (b) urban runoff or sewage going out of a CSO becomes part of the CSO values; (c) atmospheric fallout on land is a part of urban runoff, and only atmospheric fallout on water is listed separately; and (d) industrial discharges going to sewage treatment plants are a part of the sewage values, and only industries discharging directly onto waters are listed separately.

The nature of annual pollutant input inventories should be kept in mind. There are no completely steady discharges into the bay. Municipal plants receive more flow and higher concentrations during the day than during the night; industrial sources discharge more during the day; urban runoff occurs only during and following rain events; the time and location of oil spills cannot be predicted. The nature of these spatial and temporal variabilities of each input constitutes an important consideration for several management decisions.

THE INVENTORY

Graphic presentations of the various sources of organic contaminants, such as petroleum hydrocarbons and polycyclic aromatic hydrocarbons, and of selected metals, are given in Figure 2. It becomes obvious very quickly that only one general statement can be made about the sources of toxic pollutants to the aquatic environment: each pollutant has different major sources. We have shown three classes of hydrocarbons in Figure 2: total petroleum hydrocarbons, lower molecular weight (two rings) polycyclic aromatic hydrocarbons, and higher molecular weight (three rings or more) polycyclic aromatic hydrocarbons. For each of these hydrocarbon classes, the major entry pathway is different in the Narragansett Bay watershed. While urban runoff accounts for 48 percent of the total hydrocarbons, it accounts for only 3 percent of the two-ring PAHs. We have observed that two-ring PAHs, while found in significant concentrations in used crankcase oil and presumably also in drips of crankcase oil on the street surface, seem to be lost by weathering on the street prior to incorporation in urban runoff. These lower molecular weight PAHs in petroleum products discharged to the sewer system are not exposed to such weathering; thus, the major sources of two-ring PAHs represent fresh, unweathered oil in sewage effluent. The PAHs with three or more rings formed during combustion of fossil fuels are not lost via weathering—at least not to the same extent as the lower molecular weight compounds found—but are in lower concentrations in used crankcase oil and sewage effluents. Atmospheric deposition becomes more important for these PAHs than for the other hydrocarbons. Preliminary calculations suggest that atmospheric deposition on land surfaces can account for 50 percent of the PAHs with three or more rings in urban runoff and, thus, about 10 percent of these PAHs in sewage. Fallout of PAHs with three or more rings from the atmosphere can directly or indirectly account for over half the entry of such PAHs to Narragansett Bay.

The metals also have varied sources (see Fig. 2). The primary source of lead in Narragansett Bay is from urban runoff, presumably due to the use of leaded fuel in automobiles. The lead is emitted through the exhaust system.

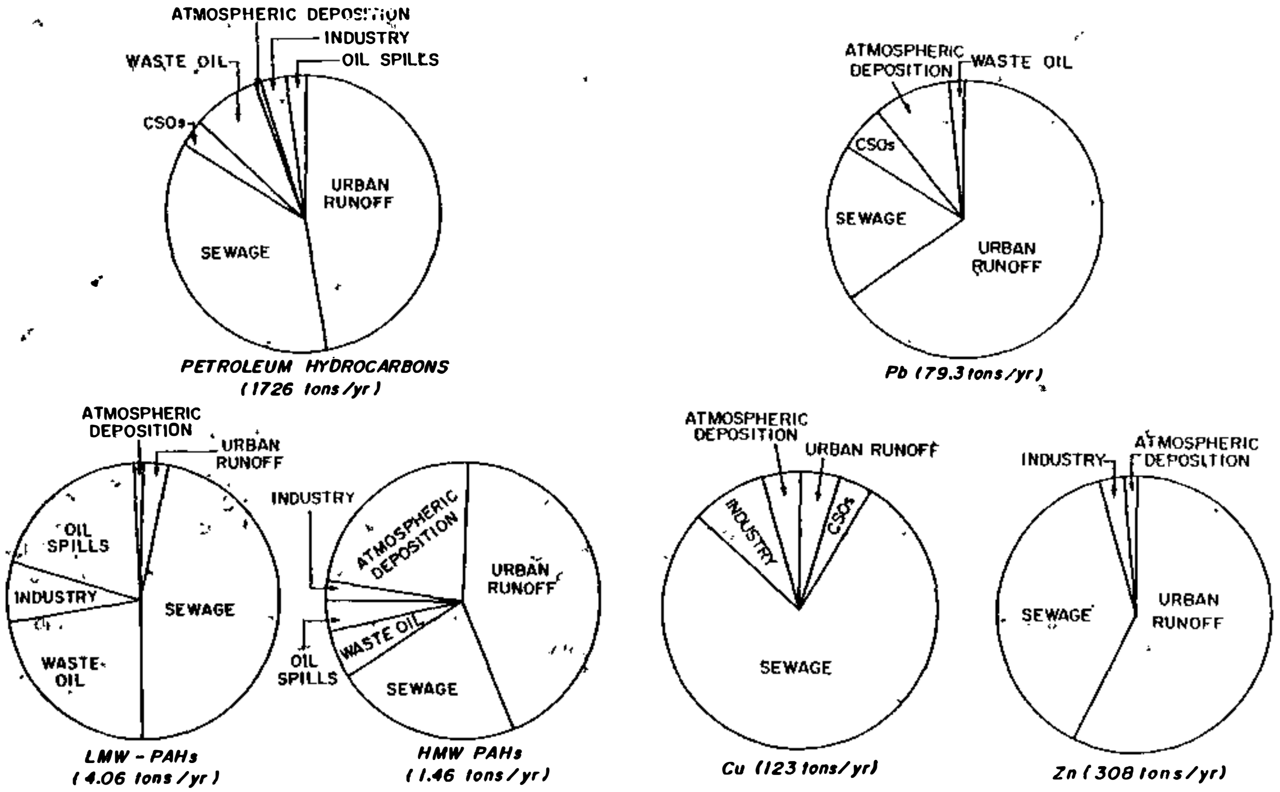

Figure 2.—Pathways of pollutant entry into the Narragansett Bay watershed.

When it is incorporated in crankcase oil, it is a component of the oil drips. While this source of hydrocarbons is the predominant contributor to hydrocarbons in urban runoff, oil drips, per se, are only a minor source (15 percent) of the lead in runoff (Latimer, 1984). Copper entering Narragansett Bay comes from sewage treatment plants, with the Providence plant contributing over half of the bay's copper content. The copper comes from industrial discharges to the sewer system from metal-finishing and electroplating industries. For Zn, both sewage treatment plants and urban runoff are important sources.

WATER BODY VERIFICATION

Recently, we conducted an experiment to determine the impact of a rain event on the water quality of the Pawtuxet River. The rain event also afforded us the opportunity to properly evaluate the application of urban runoff loading factors developed in our earlier study. We combined our urban runoff data with Pawtuxet River land use data to estimate the urban runoff loads we anticipated for this storm. A comparison of the predicted urban runoff load to the river with the actual load we observed through river monitoring is given in Table 3. The actual and predicted discharge rates agreed within a factor of 2 for 9 of the 12 components we examined. All of the rates agreed within a factor of 3.

These data also allowed us to evaluate how important urban runoff components are to the water quality of the river during storms. The background discharge rates (resulting from point sources) were minor in comparison with the wet weather contributions for most of the PAHs, HC, Pb, and Zn. Concentrations of Cd and Cu were not greatly affected by stormwater inputs. During this storm, 85 percent of the PAH's, 79 percent of the hydrocarbons, 82 percent of the Pb, and 63 percent of the Zn were due to wet weather inputs.

In summary, on an annual basis, urban runoff was the major source of hydrocarbons and lead to Narragansett Bay, and a significant source of PAHs and zinc to this estuary. The urban runoff loading rates we determined were later found to predict accurately the actual wet weather inputs to one of the bay's tributaries. Changes in tributary discharge rates during wet weather conditions can be substantial.

Table 3.—Comparison of actual Pawtuxet River discharge rates with predicted urban runoff loads (Nov. 3–4, 1983, 1.39 cm rainfall, river station #9).

	Actual discharge	Background dry weather discharge	Urban runoff from monitoring data	Predicted urban runoff rate from land use data	Ratio of actual to predicted rate
Pb	3770 gm	667 gm	3110 gm	6230 gm	0.50
Zn	258 kg	96.4 kg	162 kg	106 kg	1.52
Cd	455 gm	369 gm	86 gm	46 gm	1.82
Cu	11.9 kg	9.8 gm	2.1 kg	3.8 kg	0.55
HC	101 kg	20.9 kg	80.0 kg	200 kg	0.40
PAH	240 gm	36.7 gm	204 gm	267 gm	0.76

REFERENCES

Brinkman, D.W., A.L. Whisman, N.J. Weinstein, and H.R. Emmerson. 1981. Environmental Resource Conservation and Economic Aspects of Used Oil Recycling. DOE/BE TC/RI-80/11. U.S. Dep. Energy, Washington, DC.

Hoffman, E.J. 1983. A simple model to predict CSO discharges from urban runoff and treatment plant influent data. Unpubl. mss.

Hoffman, E.J., E. Askins, J.G. Quinn, and J. Marchand. 1981. Used crankcase oil disposal practices: implications to recycling programs. Int. Conf. Energy Ed., Providence, RI. Aug. 4-7, 1981.

Hoffman, E.J., C.G. Carey, G.L. Mills, and J.G. Quinn. 1984. The magnitude and effect of wet weather pollutant inputs to a municipal wastewater treatment facility served by a combined stormwater sewage collection system. Unpubl. mss.

Hoffman, E.J., A.M. Falke, and J.G. Quinn. 1980. Waste lubricating oil disposal practice in Providence, Rhode Island: potential significance to coastal water quality. Coastal Zone Manage. J. 8: 337.

Hoffman, E.J. et al. 1985. Stormwater runoff from highways: chemical and physical characteristics and implications for treatment. Water Air Soil Pollut. In press.

Hoffman, E.J., J.S. Latimer, C.D. Hunt, and J.G. Quinn. 1983. Inputs of pollutants into Rhode Island rivers via urban runoff. Rep. Rhode Island Dep. Environ. Manage. Div. Water Resour. Providence.

Hoffman, E.J., J.S. Latimer, G.L. Mills, and J.G. Quinn. 1982. Petroleum hydrocarbons in urban runoff from a commercial land use area. J. Water Pollut. Control Fed. 54: 1517–25.

Hoffman, E.J., G.L. Mills, J.S. Latimer, and J.G. Quinn. 1983. Annual input of petroleum hydrocarbons to the coastal environment via urban runoff. Can. J. Fish. Aquat. Sci. 40 (Suppl. 2) 41–53.

Hoffman, E.J. et al. 1984. Urban runoff as a source of polycyclic aromatic hydrocarbons to coastal waters. Environ. Sci. Technol. 18: 580–7.

Latimer, J.S. 1984. Characterization of the sources of hydrocarbons in urban runoff from relationships of organic distributions and metal content. M.S. Thesis. Dep. Chemistry, Univ. Rhode Island.

Marchand, J.P., E. Askins, L. LeFebvre, and M. Lehder. 1980. Used Oil Recovery in South Carolina. S.C. Joint Leg. Comm. Energy, Columbia.

Martin, B.K., and D. Robadue. 1983. Estimates of combined sewage and storm water flows from the city of Providence. Coastal Resour. Center, Univ. RI, Narragansett.

Metcalf and Eddy, Inc. 1983. Demonstration of Water Quality Benefits for Rhode Island Combined Sewer Overflow Control Projects. Rep. to R.I. Dep. Environ. Manage., Providence.

Olsen, S., and V. Lee. 1979. A Summary and Preliminary Evaluation of Data Pertaining to the Water Quality of Narragansett Bay. Coastal Resour. Center, Univ. R.I., Narragansett.

Pruell, R.J. 1983. Personal comm. Graduate School Oceanogr. Univ. Rhode Island, Narragansett.

U.S. Environmental Protection Agency. 1984. Water Plann. Div. Final Rep. Nationwide Urban Runoff Prog. Washington, DC.

CHESAPEAKE BAY NONPOINT SOURCE POLLUTION

JOSEPH MACKNIS

Chesapeake Bay Liaison Office
Annapolis, Maryland

ABSTRACT

In 1976, the EPA was directed by Congress to conduct an in-depth study of the Chesapeake Bay, its resources and its management. The goal was "to protect and preserve the quality of the Chesapeake Bay by effectively managing its uses and resources." In completing the $27 million study, the EPA Chesapeake Bay Program developed a watershed model to estimate point and nonpoint source loadings to the Bay and to evaluate management strategies in reducing nutrient loadings. Model production runs indicate that nonpoint sources contribute between 31 and 64 percent of the phosphorous load and between 62 and 81 percent of the nitrogen load to the Bay system depending upon annual rainfall conditions. Most of the phosphorous loadings to Chesapeake Bay come from point sources which are concentrated close to tidal waters, while most of the nitrogen enters the Bay from nonpoint sources located throughout the basin, primarily runoff from agricultural croplands. Model simulations indicate that a Level II best management practice such as conservation tillage is a cost-effective management alternative. In response to the findings of the Chesapeake Bay Program, the Bay States of Maryland, Pennsylvania, and Virginia initiated agricultural (and urban) nonpoint source control programs that increase technical and financial assistance to farmers and augment demonstration projects and education efforts. The Program is tracking these efforts and attempting to evaluate their effectiveness in controlling nonpoint source pollution.

INTRODUCTION

In 1976, the U.S. Environmental Protection Agency (EPA) conducted an in-depth study of the Chesapeake Bay, its resources and management "to protect and preserve the quality of the Chesapeake Bay by effectively managing its resources." EPA fulfilled this Congressional mandate through the Chesapeake Bay Program (CBP), which documented declines in living resources such as submerged aquatic vegetation (SAV), striped bass, shad, oysters, and clams. These declines parallel changes in water quality which include increases in nutrient concentrations, chlorophyl *a*, turbidity, and toxic chemicals and decreases in levels of dissolved oxygen.

Specifically, submerged aquatic vegetation has declined dramatically throughout the Bay; landings for freshwater spawning fish, such as shad, alewife and striped bass, have decreased in recent years; oyster spat set also has declined significantly in the past 10 years. Nutrient increases (primarily nitrogen and phosphorus) in many areas of the Bay have led to declining water quality. Elevated levels of heavy metals and toxic organic compounds are found in Bay water and sediment; and the amount of Bay water showing low (or no) dissolved oxygen in the summer is estimated to have increased 15-fold in the last 30 years.

The $27 million research study attributes the decline to excessive nutrients and, to a lesser degree, toxic effluents and sedimentation. The nutrients, primarily from municipal waste discharges and agricultural runoff, spur the growth of algae that deplete oxygen from the water and prevent sunlight from reaching the submerged aquatic vegetation that provides critical habitat to the Bay's living resources. Sediment and toxic effluents also directly affect vegetation and fish. This paper focuses primarily on nutrient pollution.

SOURCES OF NUTRIENTS

The sources of nutrient loadings to the Chesapeake Bay are influenced by population growth and land use within the 64,000 mi^2 catchment area that includes portions of six States and the District of Columbia (Fig. 1). For management purposes the area was divided into the eight major drainage basins also shown in Figure 1. Basinwide, the population grew 49 percent between 1950 and 1980 and is projected to grow an additional 15 percent by the year 2000, to a total of 14.6 million. Population growth contributes to the major point source of nutrients to the Bay, sewage treatment plants. The other major type of point source in the basin is industrial wastewater.

In addition to increasing sewage treatment plant discharge volume, population increases drive changes in land use. The percentage of land in urban and residential usage has increased 282 percent since 1950 and, although agriculture land use has declined somewhat, the agricultural and livestock practices employed have intensified.

CHESAPEAKE BAY WATERSHED MODEL

Estimates of sources and loadings of nutrients to the Bay as well as the efficacy of management strategies to control them, were determined with the assistance of a Bay-

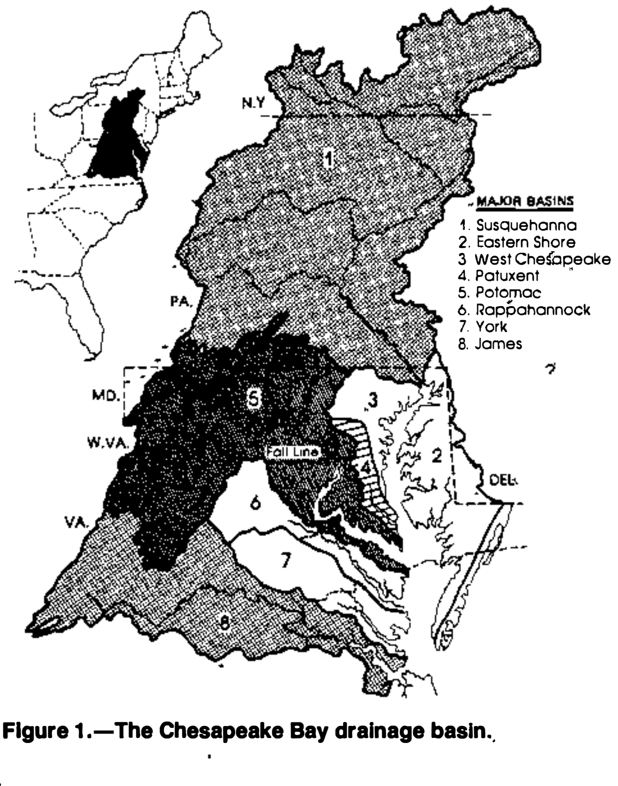

Figure 1.—The Chesapeake Bay drainage basin.

wide water quality model. The model (Hartigan et. al. 1983), simulated nonpoint source loadings between March 1 and Oct. 31, the period most important in terms of algal growth in the Chesapeake Bay. Model input data were based on 1980 point source loadings and land use. The U.S. Geological Survey (USGS) rainfall records from a wet year (1975), dry year (1966), and an average year of rainfall (1974), were used to estimate the nonpoint loads. The basin model routed nonpoint (and point) source loads to the fall line, simulating the physical, chemical, and biological processes that transform the pollutants as they are transported downstream.

Model production runs indicate that the total nutrient load to the Bay varies according to rainfall conditions (Fig. 2) and that the relative amounts of point and nonpoint source loadings to the Bay similarly change with rainfall conditions. Baywide, nonpoint sources contribute from 31 to 64 percent of the phosphorus load (39 percent under average rainfall conditions) and from 62 to 81 percent of the nitrogen load (67 percent = average). Point sources contribute from 36 to 69 percent of the phosphorus load and 19 to 38 percent of the nitrogen load, depending upon the annual rainfall conditions; under average conditions, point sources contribute 61 percent of the phosphorus load and 33 percent of the nitrogen.

Figure 3 illustrates the point and nonpoint source loadings from each of the major basins discharging to Chesapeake Bay during an average rainfall year. Collectively, the three major tributaries to the Bay, James, Potomac, and Susquehanna contribute 30 percent of the nonpoint source load and 70 percent of the total phosphorus load. For nitrogen, they contribute 55 percent of the nonpoint

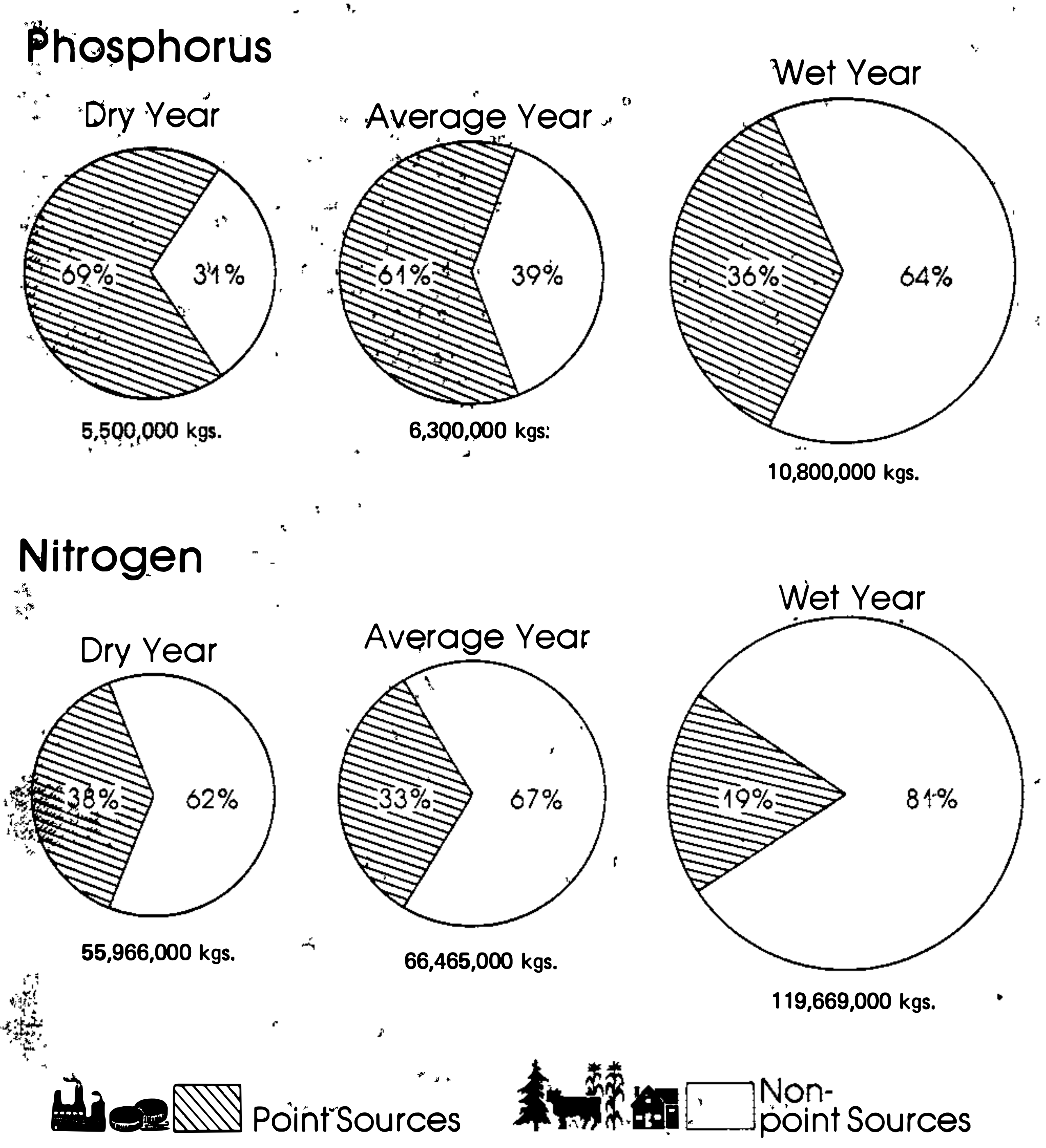

Figure 2.—Bay-wide nutrient loadings (March to October) under dry, average, and wet conditions.

source load and 78 percent of the total load during average rainfall conditions. The James is dominated by point sources while the Susquehanna is dominated by nonpoint sources; the Potomac has a more balanced mixture. To be effective, nutrient control strategies must recognize the unique nature of each basin and the relative contributions of point and nonpoint sources of nutrients within each.

Figure 4 illustrates which basins are dominated by point and nonpoint sources. It clearly shows that point sources are concentrated in sub-basins adjacent to Chesapeake Bay; essentially the urban corridor between Baltimore, Maryland, and Washington, D.C., and the fall line city of Richmond, Virginia. These point-source-dominated areas have high population densities and consequently, large volumes of wastewater discharged from sewage treatment plants. Model estimates of point and nonpoint source loads for each major drainage basin from above and below the fall line are summarized in Tables 1 and 2. They indicate that croplands generate a large portion of the total nutrient load and are by far the major nonpoint source basinwide. Croplands contribute from 27 to 53 percent of the total phosphorus load and from 60 to 75 percent of the total nitrogen load in average and wet years respectively.

In contrast, "other" nonpoint sources, which include runoff from pasture, urban, and forest lands, contribute only 11 to 12 percent of the total phosphorus and 6 to 7 percent of the total nitrogen load under similar rainfall conditions. However, the low percentages do not necessarily indicate that these nonpoint sources, especially urban sources, are not a problem in Bay waters. In urban areas adjacent to critical habitats such as tidal freshwater spawning grounds, the accumulated pollutants flushed from streets and residential areas during wet weather contribute significant quantities of both conventional and toxic pollutants.

EVALUATION OF MANAGEMENT ALTERNATIVES

In addition to estimating point and nonpoint source nutrient loadings, the model evaluated the relative effectiveness of point and nonpoint source controls and estimated year 2000 loads. The point source strategies simulated by the model were primarily technology-based controls that limit the effluent concentration of nitrogen and phosphorus. A phosphorus ban and future (year 2000) loadings were also evaluated.

For nonpoint sources, the model estimated the impact of changes in tillage practices and, in the lower Susquehanna, the simultaneous strip cropping and conversion of all conventional tillage cropland in each basin to conservation tillage. The factor in the model that represents vegetative cover was the primary adjustment made to simulate this option. A point source effluent limitation of 2 mg/ total phosphorus was also tested under existing and future conditions. Agricultural land use was assumed to remain unchanged in the year 2000 model simulations.

Table 3 contains the estimated reductions in nutrient loads, by major basin, achieved in the conservation tillage model simulation during average and wet rainfall conditions. Conservation tillage is more effective in reducing phosphorus than nitrogen loads because phosphorus is transported in the particulate form adsorbed to sediment particles. Conservation tillage minimizes disturbances of the soil surface and significantly reduces soil loss.

Nitrogen, however, is mostly soluble and what does not wash off is taken up by plants or transformed to gas and percolates down into the ground water, some of which flows into adjacent waterbodies. The complicated nutrient forms and pathways, along with diverse crop and pastureland management systems, illustrate the need to implement separate best management practices (BMP's) to control both nitrogen and phosphorus.

The effectiveness of conservation tillage is related to current cropping practices, soil type, slope, and other factors that vary among river basins. In some areas, physical conditions preclude its use. Furthermore, the benefits of conservation tillage in preventing sediment and nutrient losses must be weighed against the increased use of herbicides associated with this practice and other farm management considerations.

Data from model simulations in the lower Susquehanna indicate that the simultaneous implementation of conservation tillage basinwide and strip cropping in the lower Susquehanna would reduce existing (1980) total phos-

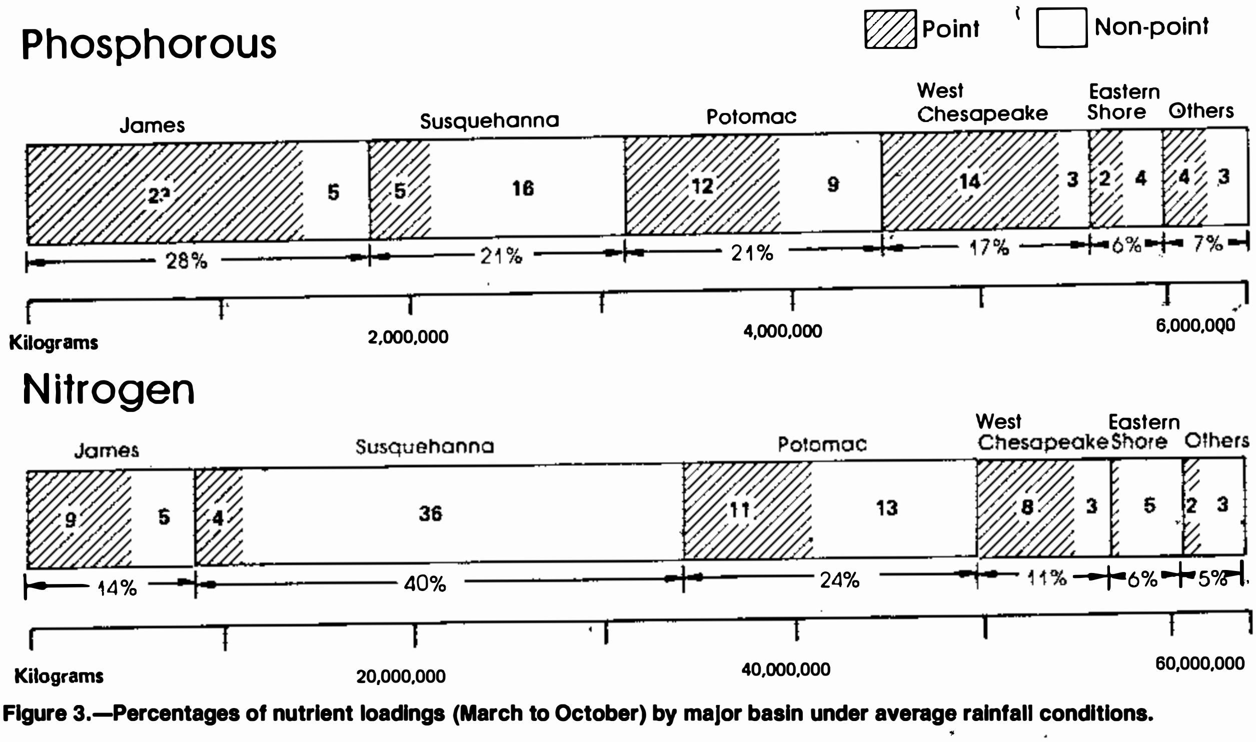

Figure 3.—Percentages of nutrient loadings (March to October) by major basin under average rainfall conditions.

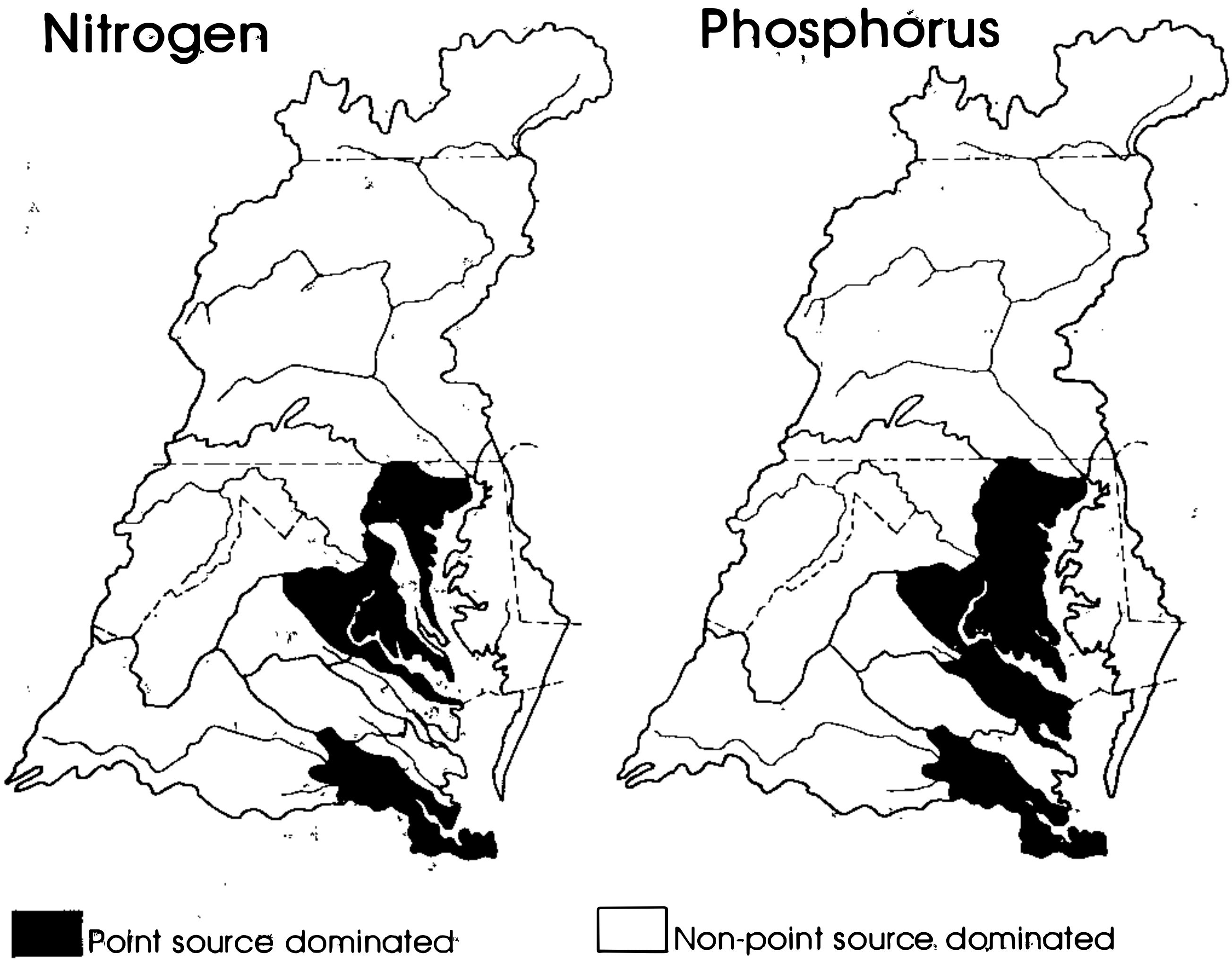

Figure 4.—Relative importance of point and nonpoint source of nutrients within major basins.

Table 1.—Phosphorus loadings to Chesapeake Bay by major basin (March–October)

	Phosphorus (kg)			% Point source contribution			% Cropland load contribution			% Other source load source contrib.			† Total nonpoint contribution		
Basin	**Dry**	**Avg.**	**Wet**	**Dry**	**Avg.**	**Wet**	**Dry**	**Avg.**	**Wet**	**Dry**	**Avg.**	**Wet**	**Dry**	**Avg.**	**Wet**
Part A: at the fall line															
Susquehanna	941,000	1,318,000	2,864,000	24	23	12	–	60	77	–	16	11	76	76	88
Patuxent	156,000	149,000	174,000	92	90	76	–	7	19	–	3	5	8	10	24
Potomac	326,000	388,000	1,077,000	27	15	7	–	52	72		33	21	73	85	93
Rappahannock	49,000	47,000	130,000	1	1	1	–	58	75	–	41	24	99	99	99
York	30,000	35,000	151,000	7	7	2	–	74	86	–	19	12	93	93	98
James	299,000	349,000	690,000	45	36	21	–	46	63	–	18	16	55	64	79
TOTAL	1,801,000	2,286,000	5,086,000	33	28	14		53	72		19	14	67	72	86
Part B: to tidal waters (below the fall line)															
W. Chesapeake	988,000	1,087,000	1,384,000	93	85	67	–	8	25	–	7	8	7	15	23
Patuxent	59,000	68,000	130,000	79	69	36	–	19	51	–	12	13	21	31	64
Potomac	882,000	915,000	1,263,000	82	79	57	–	10	31	–	11	12	18	21	43
Rappahannock	54,000	79,000	221,000	89	61	22	–	27	69	–	12	9	11	39	78
York	39,000	65,000	208,000	84	50	16	–	27	68	–	10	8	18	50	84
James	1,325,000	1,374,000	1,570,000	96	93	81	–	3	14	–	4	5	4	7	19
Eastern Shore	345,000	379,000	962,000	44	40	16	–	50	79	–	10	5	56	60	84
TOTAL	3,692,000	3,967,000	5,738,000	87	81	56		12	36		7	8	13	19	44
Part C: Part A + Part B															
Susquehanna	941,000	1,318,000	2,864,000	24	23	12	–	60	77	–	17	11	76	77	88
Patuxent	215,000	217,000	304,000	88	83	58	–	10	33	–	7	9	12	17	42
Potomac	1,208,000	1,303,000	2,304,000	67	59	34	–	23	50	–	18	16	33	41	66
Rappahannock	103,000	126,000	350,000	47	39	14	–	39	71	–	22	15	53	61	86
York	69,000	100,000	359,000	50	35	10	–	44	76	–	6	14	50	65	90
James	1,624,000	1,723,000	2,259,000	86	81	63	–	12	29	–	7	8	14	19	37
W. Chesapeake	988,000	1,087,000	1,384,000	93	85	67	–	8	25	–	7	8	7	15	23
Eastern Shore	345,000	379,000	962,000	44	40	16	–	50	79	–	10	5	56	60	84
TOTAL	5,493,000	6,253,000	10,786,000	69	61	36		27	53		12	11	31	39	64

Table 2.—Nitrogen loadings to Chesapeake Bay by major basin (March–October)

Basin	Nitrogen (kg) Dry	Nitrogen (kg) Avg.	Nitrogen (kg) Wet	% Point source contribution Dry	% Point source contribution Avg.	% Point source contribution Wet	% Cropland load contribution Dry	% Cropland load contribution Avg.	% Cropland load contribution Wet	% Other aource load aource contrib. Dry	% Other aource load aource contrib. Avg.	% Other aource load aource contrib. Wet	† Total nonpoint contribution Dry	† Total nonpoint contribution Avg.	† Total nonpoint contribution Wet
Part A: at the fall line															
Susquehanna	21,500,000	26,500,000	48,000,000	10	10	5	–	85	91	–	5	4	90	90	95
Patuxent	580,000	536,000	809,000	71	65	41	–	29	53	–	6	6	29	35	59
Potomac	6,270,000	7,500,000	17,800,000	10	10	10	–	83	84	–	7	6	90	90	90
Rappahannock	695,000	727,000	1,680,000	10	10	10	–	72	78	–	18	12	90	90	90
York	380,000	370,000	1,264,000	10	10	10	–	78	82	–	12	8	90	90	90
James	1,760,000	2,300,000	5,030,000	10	9	8	–	73	78	–	18	14	90	91	92
TOTAL	31,185,000	37,933,000	74,559,000	11	11	7		83	88		6	5	89	89	93
Part B: to tidal waters (below the fall line)															
W. Chesapeake	6,179,000	7,265,000	10,038,000	85	72	52	–	20	40	–	8	8	15	28	48
Patuxent	439,000	596,000	1,278,000	48	35	16	–	55	75	–	10	9	52	65	84
Potomac	8,094,000	8,399,000	11,394,000	77	74	55	–	17	37	–	9	8	23	26	45
Rappahannock	279,000	611,000	2,047,000	37	17	5	–	73	89	–	10	6	63	83	95
York	315,000	688,000	2,255,000	34	15	5	–	76	90	–	9	5	66	85	95
James	6,272,000	7,013,000	8,913,000	88	79	82	–	15	32	–	6	6	12	21	3
Eastern Shore	3,269,000	3,973,000	9,500,000	13	10	4	–	83	92	–	7	4	87	90	96
TOTAL	24,847,000	28,565,000	45,425,000	72	62	39		30	54		8	7	28	38	61
Part C: Part A + Part B															
Susquehanna	21,500,000	26,455,000	47,727,000	10	10	5	–	85	91	–	5	4	90	90	95
Patuxent	1,015,000	1,133,000	2,088,000	61	49	26	–	43	66	–	8	8	39	51	74
Potomac	14,367,000	15,944,000	29,167,000	48	44	28	–	48	66	–	8	6	52	55	72
Rappahannock	975,000	1,339,000	3,734,000	17	13	7	–	72	84	–	15	9	83	87	93
York	630,000	1,058,000	3,492,000	22	13	7	–	77	87	–	10	6	78	87	93
James	8,032,000	9,320,000	13,945,000	71	62	43	–	29	49	–	9	8	29	38	57
W. Chesapeake	6,179,000	7,265,000	10,038,000	85	72	52	–	20	40	–	8	8	15	28	48
Eastern Shore	3,269,000	3,973,000	9,500,000	13	10	4	–	83	92	–	7	4	87	90	96
TOTAL	55,967,000	66,487,000	119,691,000	38	33	19		60	75		7	6	62	67	81

Table 3.—Estimated nutrient reductions achieved in level two model simulation under average and wet conditions (March–October).

Basin	% Phosphorus load reduction (kg reduction) Avg. year	% Phosphorus load reduction (kg reduction) Wet year	% Nitrogen load reduction (kg reduction) Avg. year	% Nitrogen load reduction (kg reduction) Wet year
Susquehanna	16.0 (211,000)	32.0 (916,000)	1.3 (356,000)	8.0 (3,818,000)
West Chesapeake	2.3 (25,000)	14.4 (200,000)	1.7 (120,000)	10.9 (1,098,000)
Eastern Shore	14.3 (54,000)	43.7 (421,000)	6.3 (250,000)	23.9 (2,273,000)
Patuxent	1.1 (2,000)	14.2 (43,000)	0.8 (9,000)	11.6 (241,000)
Potomac	4.3 (56,000)	25.4 (594,000)	1.3 (207,000)	11.1 (3,228,000)
Rappahannock	5.1 (6,000)	35.0 (122,000)	1.9 (25,000)	18.0 (669,000)
York	6.7 (8,000)	37.0 (141,000)	2.5 (26,000)	20.0 (436,000)
James	0.8 (15,000)	9.5 (214,000)	0.5 (49,000)	7.6 (1,066,000)
Basin-wide	6.5 (377,000)	24.5 (2,651,000)	1.6 (1,042,000)	10.7 (12,612,000)

phorus and nitrogen loads from the Susquehanna 22 and 5 percent respectively. This indicates that significant basinwide reductions in nutrient loadings, including nitrogen, can be achieved through appropriate BMP's. Final decisions, however, should consider agricultural strategies that leave the specific BMP's to the discretion of farmers and soil conservationists.

CHESAPEAKE BAY NONPOINT SOURCE RECOMMENDATIONS (NUTRIENTS)

The watershed model showed nutrient loads to the Chesapeake can be reduced through control strategies. The Bay community supports reductions to improve Bay condition. Although it is very difficult to predict with confidence water quality or ecological response in the Bay, enough is known today to call for limiting nutrient loads to Bay waters.

In 1983 the Chesapeake Bay Program developed the following specific recommendations to control and reduce nonpoint pollution (Tippe et al. 1983).

- The States and EPA, through the Management Committee, should develop a detailed nonpoint source control implementation program as part of a basinwide water quality management plan.
- The U.S. Department of Agriculture and the EPA, in consultation with the Management Committee, should strengthen and coordinate their efforts to reduce agricultural nonpoint source pollution to improve water quality in Chesapeake Bay.
- Federal agencies, States, and counties should develop incentive policies by July 1, 1984, that encourage farmers to implement BMP's.
- The State, counties, and municipalities located in

subbasins adjacent to tidal-fresh and estuarine segments of Chesapeake Bay and its tributaries should implement fully and enforce existing urban stormwater runoff control programs.

• The States of Maryland and Virginia and local governments should consider strengthening wetland protection laws to include nontidal wetlands because of their value as nutrient buffers and living resource habitat.

FEDERAL AND STATE INITIATIVES

Following the publication of the Chesapeake Bay Program findings and results, a conference was convened by the Governors of Virginia, Maryland and Pennsylvania, the Mayor of the District of Columbia, the EPA Administrator, and the Chesapeake Bay Commission. The conference marked the beginning of a coordinated visible effort to correct problems identified by Chesapeake Bay Program reports.

The centerpiece of the commitments made by the sponsors was the "Chesapeake Bay Agreement of 1983" which recognized the need for a regional management structure to support and enhance a regional cooperative approach for the environmental management of the Bay. The Agreement provided the authority to establish an Executive Council, an Implementation Committee, and a Chesapeake Bay Liaison Office. The Executive Council is to assess and oversee the implementation of coordinated plans to improve and protect the water quality and living resources of the Chesapeake Bay estuarine system. The Implementation Committee will coordinate technical matters and develop and evaluate management plans. The Committee has established subcommittees for Planning, Monitoring, Modeling and Research, and Data Management. The Liaison Office will advise and support the Council and Committee.

The Liaison Office has assumed the lead in coordinating Federal clean-up efforts and has negotiated Memoranda of Understanding (MOU) with five other Federal agencies whose activities impact Bay resources and water quality. These agencies include: U.S. Fish and Wildlife Service (F&WS), the Soil Conservation Service (SCS), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers (COE), and the U.S. Geological Survey (USGS).

All of the MOU agencies pledge cooperation in areas of mutual interest and support of the goals of the Chesapeake Bay Agreement. The SCS has deployed 10 additional people to work specifically in the Chesapeake Bay drainage basin to help train State and Federal agency personnel in the application of best management practices to control nonpoint source pollution from agricultural lands.

NOAA will work with EPA in monitoring trends in the Bay. USGS will work with other agencies in developing mapping techniques and evaluating impacts of groundwater pollution on the Bay. F&WS will work with other agencies to evaluate certain wetlands activities and assist with monitoring trends of contaminants in fish.

The Corps will provide particular help with modeling the Bay and tributaries, and work with other agencies while conducting its recently authorized Chesapeake Bay Erosion Control Study. In addition to the above MOUs the EPA has signed a Joint Resolution on Pollution Abatement in the Chesapeake Bay with the Department of Defense (DoD). The DoD has pledged to give priority consideration to funding pollution control projects and studies affecting the Bay.

Complementing these Federal efforts, the District of Columbia and the States of Maryland, Pennsylvania, and Virginia have each initiated programs to reduce pollutant loadings and to protect and restore Bay resources and habitat within their jurisdiction. For example, the District of Columbia has developed initiatives to deal with problems in the Upper Potomac Estuary which may be contributing to the decline of the Bay. The program covers point and nonpoint source pollution, provides resource management, and encourages regional cooperation. Moreover, the District of Columbia is developing a stormwater regulatory program to control new development and redevelopment after construction. A BMP manual and a homeowners BMP guidebook will complement the regulations. These products will not only reduce loadings of pollutants, but will also improve public understanding of the need to abate nonpoint source pollution.

The Maryland General Assembly appropriated $36 million in FY 1985 for a variety of point and nonpoint source pollution control strategies including $2 million cost sharing to implement agricultural BMP's and $1.4 million to hire 42 new employees to provide technical assistance to landowners in designing appropriate BMP's. Existing cost share program grants have already totaled $5 million since July, 1983. Another important component of the agricultural conservation program is an intensive informational and educational program to encourage farmer participation in pollution control activities. The overall goal of the Maryland agricultural initiative is to have conservation plans in place on farms located in "priority" areas having direct impacts on Chesapeake Bay water quality within 5 years.

Other nonpoint pollution abatement actions the State of Maryland has undertaken include:

• Increasing enforcement of the State stormwater control law that requires that streams be just as clean after nearby construction as they were before construction;

• Transferring authority for enforcing sediment and erosion control laws to the State unless counties can demonstrate they can do the job;

• Establishing rules and regulations requiring efficient design, construction, operation and maintenance of agricultural drainage projects;

• Providing grants to local governments for a forest buffer program;

• Providing construction funds for shoreline erosion control; and

• Increasing appropriations for the conservation easement program.

For the 1984-86 biennium, the 1984 General Assembly of Virginia appropriated $10.4 million for Chesapeake Bay initiatives, including $2.5 million for an agricultural pollution control plan. The largest single element in the plan is a program to cost share the installation of BMP's with farmers.

This program employs a multiple level targeting strategy. At the first level, all farmers within Virginia's portion of the Bay watershed are eligible for cost-sharing assistance on certain, specified, water-quality-related BMP's. The second level targets cost-sharing funds for certain practices to subbasin areas with intensified cropland and animal waste practices. The third level, a demonstration project, targets a small agricultural watershed for an intensive BMP promotion program. Continuous water quality monitoring at the site should give an indication of the water quality impacts of the BMP program over time.

The Virginia agricultural control plan also established a process for identifying priority areas where technical assistance, demonstration projects and education programs will be targeted. The goal of the program is to increase implementation of BMP's by farmers and land developers within the Chesapeake Bay drainage basin. In addition to the agricultural initiative, the Commonwealth has established other nonpoint initiatives demonstrating pollutant control from urban areas and assisting low income shoreline residents with sanitation deficiencies to install septic tanks and other facilities.

The Commonwealth of Pennsylvania has also initiated a comprehensive agricultural nonpoint source control program with the commitment of $2 million in State and Federal funds in its fiscal 1985 budget. One million dollars in financial assistance is available to assist Pennsylvania farmers implement BMP's to control soil and nutrient loss. Educational programs will help Pennsylvanians understand the Bay's problems, their contributions to those problems, and explain ways to mitigate those problems. Additional educational programs, particularly for farmers, will stress the importance and potential savings from nutrient management.

In addition, tillage demonstration projects will compare yields from different practices and show proper tillage techniques. A pesticides management program will provide information on appropriate projects and a manure management program will stress on and off site use of manure as a resource. The program's goal is to accelerate the implementation of best management practices on agricultural land. It focuses on animal waste and nutrient management. The initial phase targets seven watersheds in the lower Susquehanna River with high livestock density and intensive cropping practices. The program will later be extended to other watersheds.

IMPLEMENTATION GRANTS TO THE STATES

To assist the States and the District of Columbia in developing programs to improve Bay water quality and resources, EPA awarded $3 million in implementation grants in 1984. It is anticipated that the current Administration will provide $10 million for each of the next 4 years. Approximately $7.2 million will be available annually for State implementation grants. Although various types of projects are eligible for funding, FY 1985 grant criteria require that 75 percent of the grant amount be applied towards nonpoint source controls. Structural, educational, and demonstration projects which address a significant pollution source in geographic areas of concern will also receive priority.

The States and EPA have been further directed that in selecting projects to be funded by Chesapeake Bay Implementation grants, they must consider the following criteria:

- The project's potential contribution to reductions in pollutant loadings or improvements in resource habitat;
- The appropriateness and cost-effectiveness of the project. Higher priority should be given to projects located in designated critical watersheds;
- The potential beneficial effect of the project on ecologically important areas in the Bay;
- The unavailability of other Federal funding. For example, projects that can be funded through EPA's construction grants program should not be considered;
- The project should be included in the Restoration and Protection Plan of 1985.
- The project represents an incremental step in a phased long-term commitment to determine effective new programs or is part of a comprehensive abatement program in a specific hydrologic unit or watershed.
- NPS implementation efforts should be concentrated in targeted hydrologic units or targeted to types of sources for which solutions are not known.

OUTLOOK

The Chesapeake Bay Program findings clearly indicate that the Bay's water and sediment quality have degraded and many of its important living resources have declined. Given the increasing environmental stress projected to be placed on the Bay resulting from population increases and land use changes, it will be difficult to halt this decline and even more difficult to reverse it. It is generally agreed, however, that reducing the nutrient loadings to the Bay from point and nonpoint sources will begin to restore the environmental quality of the Bay.

Fortunately the States, EPA, and other Federal agencies already have begun control efforts to address observed Bay problems. While scientists, however, cannot predict with confidence how much the current and proposed initiatives will reduce nutrient (and toxic) loadings to the Bay nor how quickly or extensively the Bay will respond, it is generally agreed that a long-term strategy is necessary to restore and protect the Chesapeake Bay.

So that mid-course correction in control strategies can be made, the effectiveness of agricultural nonpoint source programs must be assessed. It is therefore necessary that a monitoring and tracking system be established. The monitoring system should include both water quality and biological monitoring and provide input for model development to project results from BMP implementation. Effective monitoring will identify areas where BMP implementation measurably improved water quality. The tracking system will help document where and under what conditions specific BMP's were implemented and allow calculation of their cost effectiveness. Data gathered from these parallel efforts, along with results of specific programs and projects, will help to guide the cooperative Federal and State efforts to restore and protect the Chesapeake Bay.

REFERENCES

Tippe, V.K., et al. 1983. Chesapeake Bay: a framework for action. Chesapeake Bay Progr. U.S. Environ. Prot. Agency. Natl. Tech. Inf. Serv., Springfield, VA.

Hartigan, J., et al. 1983. Chesapeake Bay Basin Model. Final rep. N. Va. Plann. Dist. Comm., Annandale, VA.

THE INFLUENCE OF NPS POLLUTION IN FLORIDA ESTUARIES: A CASE STUDY

JOE RYAN
J. H. COX
Department of Environmental Regulation
Tallahassee, Florida

ABSTRACT

A study designed to characterize the pollutant climate of 13 major bays and estuaries in Florida was carried out by examining sediment chemistry. This study provided improved interpretive tools that were used to distinguish natural versus anthropogenic metal concentrations and to help identify nonpoint sources. Results confirmed that, although elevated metals and synthetic organic compounds were present in the water column, the concentration of these constituents was well below State and Environmental Protection Agency water quality standards. These data provide a clearer understanding of pollutant trends and revealed encroachment of metal contamination in several major estuaries. The highest levels of metals and synthetic organics were found in sediments from the Miami River and Biscayne Bay. The river receives pollutants—particularly Ag, Cd, Cu, Hg, Pb, and Zn—from a variety of nonpoint sources originating from the adjacent city of Miami. The river essentially becomes a point source discharging moving contaminants into the Bay. Results from the study were used as a basis for making recommendations to State and Federal agencies for cleaning up nonpoint sources entering the Miami River.

INTRODUCTION

Nonpoint sources, especially urban stormwater, are a major source of pollution to bays and estuaries along developed coastal areas. Although the need to protect these productive environments is widely recognized, there are many deficiencies in traditional regulatory approaches.

This paper illustrates how a better understanding of sediment chemistry provides more meaningful information for assessing and managing nonpoint source discharges of metals and organic compounds. It also outlines how these techniques have recently been used in State and local attempts to eradicate the effects of existing stormwater outfalls in the Miami River and Biscayne Bay in South Florida.

Studies of contamination in coastal areas have generally focused on water quality studies in which results are compared with a State or federally established water quality standard. This preoccupation with water quality criteria is counterproductive for three fundamental reasons. First, traditional approaches relying on water quality information fail to adequately consider environmental geochemistry. Second, the use of a water quality standard alone offers little protection to the estuarine biota, most of which are linked to the sediment through food webs. Finally, the cost of carrying out water quality studies in large urbanized areas with complex nonpoint source problems can be considerable and still not provide meaningful measures of pollution. With the limited funds available to study nonpoint pollution, improvements are needed to provide the best information for the least money.

GEOCHEMICAL CONSIDERATIONS

In contrast to lake and ocean systems, the processes that affect the distribution of chemical constituents in an estuary are complex and often poorly understood. As a result, undue emphasis is often placed on inappropriate and misleading pollution indicators. Reliable interpretive tools for assessing the degree of estuarine contamination relative to background conditions are virtually nonexistent.

In Florida, eight of the 10 largest cities are surrounded by marine or brackish waters that receive a wide variety of nonpoint source discharges. As the aqueous nonpoint sources mix with brackish or marine waters in these areas, many of the materials previously suspended or dis-

Table 1.—Metal and fluoride concentrations reported for water from other regions (in µg/L)

	World rivers[1]	S.E. U.S. rivers[2]	Hudson estuary[3]	Average ocean water[1]	S.E. U.S. coastal waters[2]	Florida standard
Arsenic	1.70	0.04–0.65	—	1.50	0.70–1.60[4]	50
Antimony	1.00	—	—	0.24	—	—
Cadmium	0.02	0.002–0.02	0.1–0.5	0.01	0.01–0.03	5
Chromium	1.00	—	—	0.30	—	50
Copper	1.50	0.25–0.77	1.0–7.0	0.10	0.06–0.45	15
Fluoride	—	50–100	—	—	1.00–1.50	5,000
Iron	40	22–120	5–96	2.00	0.30–5.60	300
Lead	0.10	0.02–0.51	—	0.003	0.012–0.083	30
Mercury	—	0.01–0.04	—	—	0.004–0.046	0.10
Nickel	0.50	0.11–0.57	0.8–11	0.20	0.29–0.47	100
Silver	0.30	—	—	0.04	—	0.05
Zinc	30	0.21–2.0	3–33	0.10	0.06–0.32	1,000

[1]From Martin and Whitfield (1983)
[2]From Windom and Smith (1984); Windom et al. (1984); Windom and Taylor (1979); Waslenchuk and Windom (1978); Windom (1971)
[3]From Klinkhammer and Bender (1981)
[4]From Waslenchuk (1978)
All references are given in the bibliography in the Manual (Ryan et al. 1984).

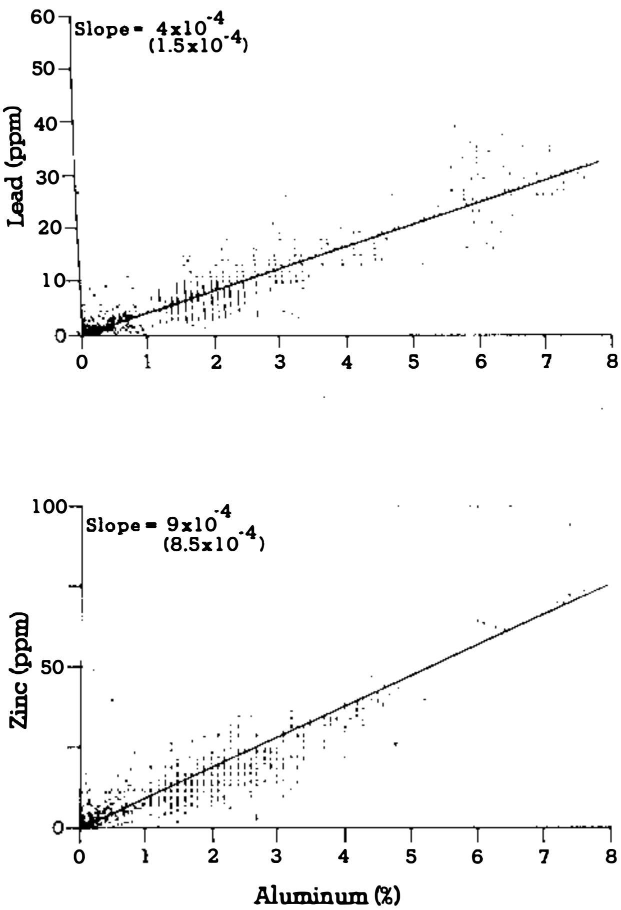

Figure 1.—Relationship between lead and aluminum, and zinc and aluminum observed in natural sediments from the southeastern United States (Windom, 1984) Slope of each line reflects the calculated metal-to-metal ratio. Values in parentheses are average ratios reported in the scientific literature (referenced in the text).

solved in freshwater are rapidly incorporated into bottom sediments by physical and chemical processes such as flocculation, precipitation and coprecipitation with scavenging. As a result, the estuarine water column shows extremely low concentrations of trace metals and organic compounds. Indeed, many of the constituents remaining in the complex saltwater matrix approach levels at or below the analytical detection limits of most chemical laboratories. More importantly, such low concentrations enhance the potential for sample contamination, leading to spurious results.

Table 1 shows the range of concentrations for several trace metals in waters throughout the United States (Klinkhammer and Bender, 1981; Martin and Whitfield, 1983; Waslenchuk, 1978; Waslenchuk and Windom, 1978; Windom and Taylor, 1979; Windom and Smith, 1984; Windom et al. 1984). The last column shows State of Florida water quality standards which are in many respects the same as EPA's. This table shows that metal levels in the water column rarely approach water quality standards. Except for sampling in the plume of a discharge, violations of water quality standards for trace metals or organic compounds in marine or brackish waters are difficult to find. It follows, then, that traditional water quality standards for metals and organic compounds—originally developed for drinking water—are inappropriate in the marine environment.

Table 1 and findings by other investigators (Pavlou and Weston, 1983; Talbot, 1983; Williams et al. 1978) indicate that bottom sediments, *not* the water column, are the real indicators of pollution in coastal environments. The concept that sediments reflect the degree to which an estuary is contaminated is straightforward, but understanding the levels of contamination is more difficult. This is especially true for metals, since they occur both naturally and as a result of man's activities. At present, there is no consensus on a reliable tool for judging the extent of metal contamination. Such tools must be developed on a regional, rather than on a national basis.

The complexities of understanding the relevance of metal levels as they occur over heterogeneous substrates of varying grain size make it extremely difficult to interpret the degree of pollution based on absolute concentrations alone (Ackerman et al. 1983; Förstner and Salomons, 1981). While many tools have been used to interpret sediment data (Brieri et al. 1975; Helz et al. 1975; Nishida et al. 1982), we have found that the ratio of a trace metal to aluminum is quite useful for interpreting the degree to which sediments are enriched with metals in Florida (Ryan and Windom, in prep.). Sediment data from 13 bays in Florida indicate that up to 70 percent of the variance in observed metal concentrations can be explained by aluminum.

Figure 1 shows this relationship between lead, zinc, and aluminum in over 1,100 uncontaminated marine sediment samples off the southeastern U.S. coast (Windom, unpubl.). As the concentration of aluminum increases, so do observed concentrations of lead and zinc. Deviations from the plotted line suggest that certain sediments are enriched in lead and zinc. In essence, these findings provide a method for normalizing the complex relationships between metal concentrations and grain size, as well as distinguishing natural from polluted sediments.

Figure 2 illustrates a broader regulatory use of the metal:aluminum relationship that we have employed to determine metal enrichment in sediments. Metal:aluminum ratios are calculated from raw data (in this case copper to aluminum) and plotted against the absolute metal concentrations and ratios reported in unpolluted sediments. If the point(s) falls in the shaded area the sediments are deemed to contain natural copper concentrations. Points

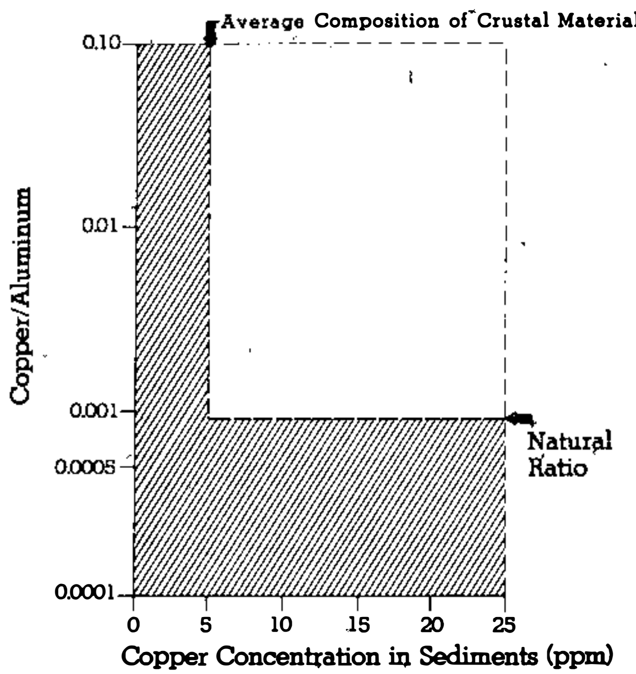

Figure 2.—Graph depicting copper concentration versus copper-to-aluminum ratio in natural sediments. Points plotted from empirical data falling within the shaded area are considered natural. Outliers indicate copper enrichment in the sediment sample.

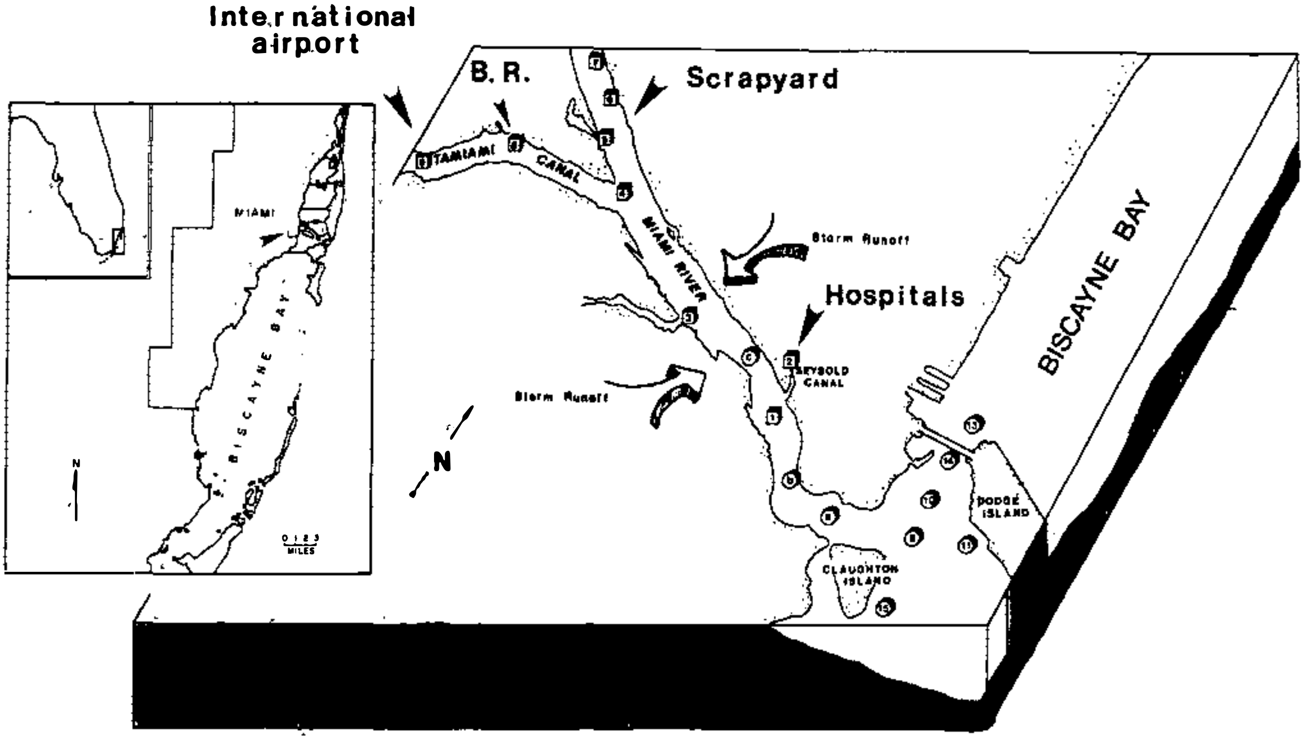

Figure 3.—Map showing relative station locations in the Miami River, Tamiami Canal, and Biscayne Bay. Major nonpoint source inputs are shown by arrows (B.R. = Boat Repair facilities).

falling outside the shaded area indicate copper contamination from human activities. Thus, the problem of comparing chemical data from areas of different grain sizes is diminished.

Using this approach, the Florida Department of Environmental Regulation (DER) studied the environmental chemistry of Florida's bays and estuaries. The study of Biscayne Bay and adjacent Port of Miami ship channels offers an example of how pollution trends can be observed more clearly and used to provide a basis for management of nonpoint source problems in a complex urban setting. In addition, an application of the previously discussed interpretive approach is demonstrated.

BISCAYNE BAY AND MIAMI RIVER STUDY

Biscayne Bay (Fig. 3) is a shallow, tropical lagoon approximately 48.27 km (35 miles) long and up to 16.09 km (10 miles) wide, with average depth of 3.66 m (12 feet). Several features make this bay unique among other urbanized coastal areas of the United States. The bay, while essentially estuarine in character, was formed as rising sea level filled in a rigid pre-existing limestone depression, rather than being formed as a drowned river valley like many other estuaries. Unlike other estuaries receiving sediments from river inflows or oceanic processes, freshwater inflows from numerous flood control canals carry little mineral detritus to the bay. Instead, most of the sediments in Biscayne Bay are produced by the local biota (Wanless, 1976).

Because of this unique arrangement, Biscayne Bay has little capacity to dilute or sequester anthropogenic contaminants that enter the South Florida coastal environment. Most pollutants enter the bay from nonpoint sources in urban Miami, traveling to the bay through canal systems, stormwater discharge pipes or ground water.

Study results indicated that port sediments were considerably enriched with trace metals, polynuclear aromatic hydrocarbons (PAH's), and polychlorinated biphenyls (PCB's). Because the most obvious source of these contaminants was a large canal, the Miami River (Fig. 3), an additional study examined the environmental chemistry of the river and its tributaries.

Figure 4 shows the results of the bulk sediment analyses for trace metals in the Miami River and in Biscayne Bay and compares metal concentrations (based on analyses of triplicate samples) with those collected in 10 other bays and estuaries in Florida. As the graph shows, metal levels in Biscayne Bay and in the Miami River are significantly greater ($p < .01$) than the average values recorded at all other study areas in Florida. Trace metal concentrations are normalized for grain size using the metal-to-aluminum ratio as discussed earlier. The Miami River is a major source of trace metals to the bay as shown by the decreasing concentration of metals from right (river) to left (bay) in Figure 4. Sediments also followed the same pattern for arsenic and chromium, not shown on this figure. While metal levels appear to gradually decrease from the river to the bay, these six metals in Biscayne Bay are still significantly higher ($p < .05$) than levels encountered at 10 other bays in the State.

A diverse group of synthetic organic compounds was also detected in the river, but few appear to have moved into the bay. PCBs (Arochlor 1254) were detected in all river sediments sampled while four of the 10 PAH's examined were also ubiquitous throughout the river. In their 2-year study of the Biscayne Bay system, Corcoran et al. (1975) found that the highest synthetic organic concentrations occured in the Miami River. While concentrations of trace metals and synthetic organic compounds are so high that *no* benthic organisms were observed during the sampling program, no violations of water quality standards were detected.

Sources of Pollution

Numerous potential nonpoint sources of pollution to the river were identified. For example, PAH's in the Tamiami Canal apear to originate from activities at the adjacent Miami International Airport complex.

Cadmium, copper, lead, silver, chromium and zinc concentrations were significantly greater ($p < .05$) at MIR-8 than at any other site in the river. This site is directly adjacent to a large boat-building and repair facility on the Tamiami Canal.

Silver and arsenic concentrations were also high in sediments from the middle portion of the river and in Seybold Canal. One possible source is a large hospital complex that discharges wastes into the canal. Silver could originate from releasing X-ray wash waters into the canal. The source of arsenic is not known. Silver appears to be fairly mobile as reflected by the enriched sediments downstream from the canal at the mouth of the river and in adjacent areas of Biscayne Bay.

Metal enrichment was also encountered in the vicinity of known stormwater discharges. Surprisingly, stormwater discharge areas draining the city bus repair facility and a large scrap metal yard, originally thought to be a source of metal contamination, showed no metal enrichment along the immediate shoreline. Because this site receives periodic freshwater discharges from a salinity control barrier during heavy rainfall, these sediments could be remobilized and moved downriver. High metal levels were found approximately 500 m below the scrapyard.

In sum, the Miami River receives pollutant inputs from numerous sources and acts as a temporary repository for these wastes. The river converts many nonpoint pollution sources into one large point source discharging into Biscayne Bay. While the total flow of contaminants from Miami's urban area to the Miami River many be no greater than for other major cities, the Miami River lacks the large volume of natural sedimentary materials that accompanies lotic inflows into other estuaries. In other urban areas such material can more effectively dilute anthropogenic inputs and sequester pollutants. Thus, the importance of understanding nonpoint pollution on a regional basis cannot be overemphasized.

NONPOINT MANAGEMENT ISSUES IN SOUTH FLORIDA

Water quality in the Miami River has been deteriorating for over 50 years. Until recently, little if any recognition has been given to the river/canal as a potentially important historical, commercial, and recreational resource. After years of neglect this attitude is changing at both the State and local levels.

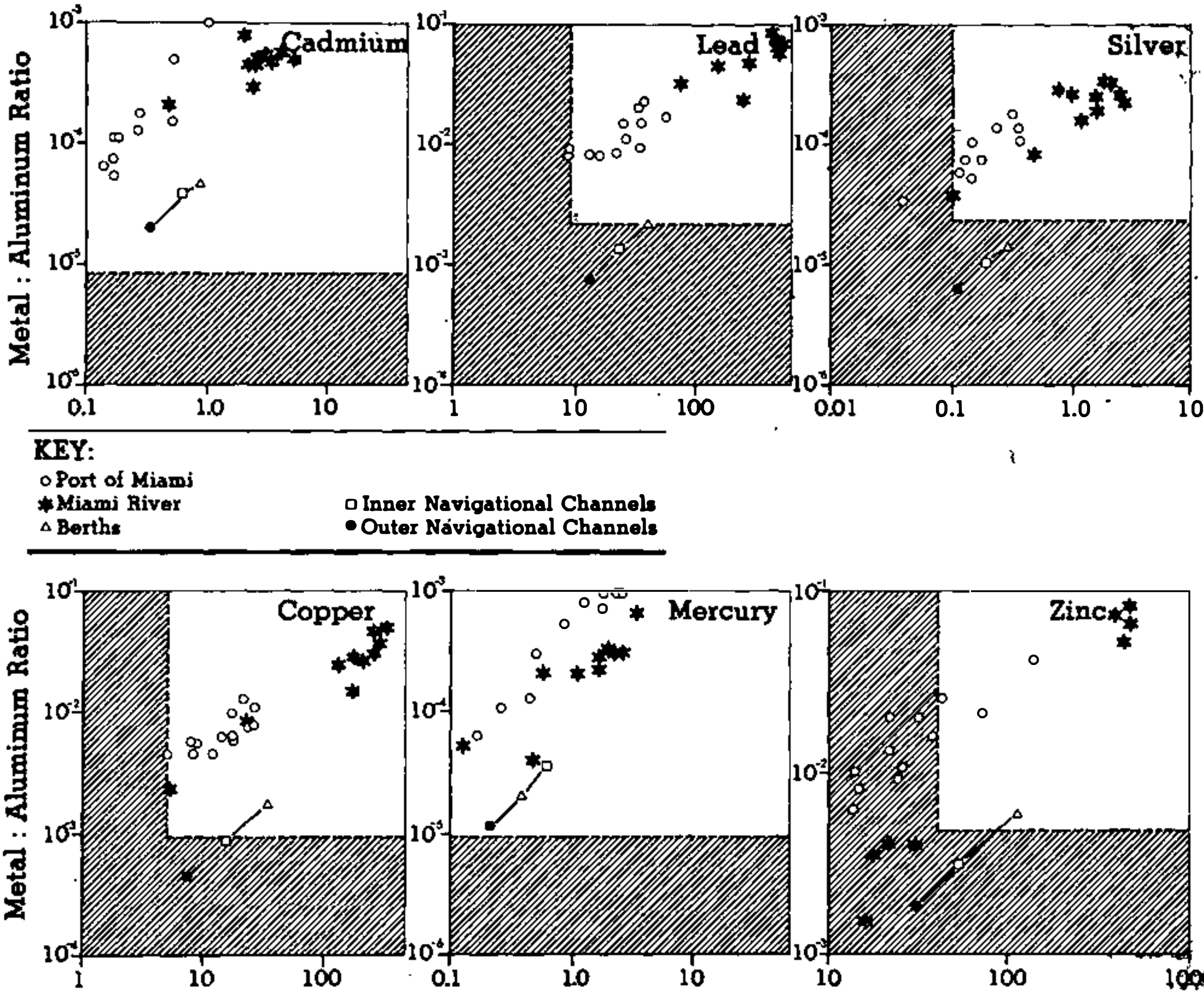

Figure 4.—Comparison of metal levels in Biscayne Bay and the Miami River with those encountered in sediments of 10 bay-estuarine systems in Florida (these are average values for inner and outer portions of the bays and for port berthing areas, which represent worst case sediments).

The Miami River Management Committee, established by executive order of Governor Graham on Dec. 15, 1983, has completed more than 1 full year of operation. The committee has presented a report setting specific, "do-able" goals and objectives for restoring and enhancing the Miami River.

Largely as a result of the sediment analyses discussed previously, scientists and agency personnel who have studied the river now believe that stormwater outfalls are a major, if not the major, source of pollutants entering the river today. Fifty-five stormwater outfalls greater than 30.48 cm (12 inches) in diameter drain roadways and the urban and industrial areas that abut the river. In addition, an unknown number of smaller outfalls, overland runoff, inwater, and upstream sources contribute to the poor water and sediment quality in the river.

Two key problems have emerged as a result of this study: (1) what to do about the movement of pollutants into Biscayne Bay from the existing Miami River sediments, and (2) how to contain nonpoint discharges currently entering the river.

Dredging contaminated river sediments is one option. However, pollutant levels are so high that disposal of the dredged material is difficult. The high cost of land in South Florida prohibits upland disposal. Offshore disposal seems unlikely because of the nature of the river sediments. Other land disposal options are severely limited by the shallowness of the Biscayne Aquifer that supplies most of South Florida's drinking water.

Regardless of whether the river is dredged, water pollution sources are being eliminated, particularly from stormwater outfalls. Priority outfalls are being redesigned by the city of Miami to percolate the first inch of runoff as a part of its current $30 million stormwater renovation program. Retrofitting those outfalls not scheduled for immediate reconstruction by the city was given a very high priority by the Committee, which has asked the State for additional funds to help eliminate or redesign the remaining outfalls that cannot be upgraded with available local funds.

The Department is concerned with the discharge of inadequately treated stormwater runoff into State waters. The agency is seeking information on potential control techniques for retrofitting or renovating existing stormwater pollution sources in heavily developed urban areas. To this end, the Department and the Committee propose to demonstrate innovative storm drain design and management practices in the lower Miami River watershed.

Because of the high cost of storm drain renovation, a prioritization process was developed to help make the most efficient use of the available funds. Sediment analyses will be used to pinpoint priority nonpoint source areas for cleanup.

REFERENCES

Ackerman, F., H. Bergmann, and V. Schleichert. 1983. Monitoring of heavy metals in coastal and estuarine sediment—a question of grain size. Environ. Technol. Lett. 4: 317–28.

Brieri, R. et al. 1982. Part III: Toxic substances *in* Chesapeake Bay Program Technical Studies: A Synthesis. U.S. Environ. Prot. Agency, Washington, DC.

Corcoran, E. 1984. Biscayne Bay Hydrocarbon Study. Rep. to Dade County Environ. Res. Managem.

Forstner, U., and W. Salomons. 1981. Trace metal analysis on polluted sediments—Part I. Environ. Technol Lett. 1: 494–517.

Helz, G.R., R.J. Huggett, and J.M Hill. 1975. Behavior of Mn, Fe, Cu, Zn, Cd, and Pb discharged from a wastewater treatment plant into an estuarine environment. Water Res. 9(7): 631–6.

Klinkhammer, G.P., and M.L. Bender. 1981. Trace metal distributions in the Hudson River Estuary. Estuar. Coast. Shelf Sci. 12: 624–43.

Martin, J.M., and M. Whitfield. 1983. The significance of the river input of chemical elements to the ocean. Pages 265–98 *in* C.S. Wong et al. Trace Metals in Sea Water, Plenum Press, New York and London.

Pavlou, S.P., and D.P. Weston. 1983. Initial evaluation of alternatives for development of sediment related criteria for toxic contaminants in marine waters (Puget Sound). Final Rep. to Region X, U.S. Environ. Prot. Agency, Seattle.

Nishida, H., M. Miyai, F. Tada, and S. Suzuki. 1982. Computation of the index of pollution caused by heavy metals in river sediment. Environ. Pollut. Ser. B. 4(4): 241–8.

Talbot, V. 1983. Lead and other trace metals in sediments and selected biota of Princess Royal Harbour, Albany, Western Australia. Environ. Pollut. (Ser. B) 5: 35–49.

Wanless, H.R. 1976. Geologic setting and recent sediments of the Biscayne Bay Region, Florida. Pages 1–33 *in* A. Thorhaug, ed. Biscayne Bay: Past/Present/Future. Special Rep. No. 5.

Waslenchuk, D.C. 1978. The budget and geochemistry of arsenic in a continental shelf environment. Mar. Chem. 7: 39–52.

Waslenchuk, D.C., and H.L. Windom. 1978. Factors controlling estuarine chemistry of arsenic. Estuar. Coast. Mar. Sci. 7: 455–62.

Williams, S.C., H.J. Simpson, C.R. Olsen, and B.F. Bopp. 1978. Sources of heavy metals in sediments of the Hudson River estuary. Mar. Chem. 6: 195–213.

Windom, H.L., and R.G. Smith. 1984. Factors influencing the concentrations and distribution of trace metals in the South Atlantic Bight. J. Geophys. Res. In press.

Windom, H.L., and F.E. Taylor. 1979. The flux of mercury in the South Atlantic Bight. Deep Sea Res. 26A: 283–92.

Windom, H.L., R.G. Smith, and M. Maeda. 1984. The geochemistry of lead in the South Atlantic Bight. Mar. Chem. (in rev.).

NONPOINT SOURCE POLLUTION CONTROL IN SMALL BAYS OF PUGET SOUND

BOB SAUNDERS
Shorelands Division
Washington Department of Ecology
Olympia, Washington

ABSTRACT

In the last 4 years, five commercial shellfish growing areas in Puget Sound have been closed because of nonpoint bacterial contamination. These have been in rural areas characterized by small acreage, semi-recreational farms, rural residential development, and moderate residential density on the saltwater frontage. With one exception, they are notable for the absence of point discharges, large commercial farming, and urban stormwater discharges. The Department of Ecology conducted a yearlong study of the water quality in two of these estuaries—Minter Bay and Burley Lagoon. The data correlated stream segment pollution levels with surrounding land use. Agricultural sources appeared to be the major problem, with failing septic tanks the suspect in some areas. The Department funded the two counties in which the watersheds occur to develop a basin plan for controlling the problem. A consultant developed three ordinances to address animal keeping practices, onsite waste disposal, and erosion control. The issues are complicated by the watershed's overlapping two counties with somewhat different sets of land use ordinances in place. Also, community reaction to the initial proposals has been adverse. The proposals are undergoing community review and may undergo considerable revision. Other efforts are being funded to continue to develop farm management plans on a voluntary basis, pending completion of a basin planning program.

Shellfish in Washington State are important. Washington is the fifth largest producer of oysters in the United States, the eighth largest producer of clams, and the only producer of the giant geoduck clams, which average 2 lbs apiece and can reach 10 lbs. Puget Sound mussels have been the winners for the last 2 years in national taste test competitions. In addition to the commercial importance, Puget Sound supports 441,000-user trips/year of recreational clam digging. The availability of freshly dug or purchased shellfish is a significant feature of traditional Puget Sound lifestyle.

Concern over the health of this resource began in 1982 after the third decertification of a commercial growing area. Oyster growers' concerns and pressures led to the initiation of a shellfish protection planning effort by the Department of Ecology (WDOE), the State agency responsible for water pollution laws and for shoreline management. A year and a half later, when the agency's Shellfish Protection Strategy was completed, the decertified areas had grown to six and the problem was getting front-page coverage in Sunday issues of the largest papers in the State.

Based on these closures, four of which were due to nonpoint sources, the Shellfish Protection Strategy identified nonpoint source pollution in watersheds draining to areas with shellfish resources as the major problem, and called for a program of basin planning to control the problem. The concept was to develop a pilot basin plan or nonpoint pollution control program in one area and then to promote the adoption and adaptation of this model in other watersheds.

The pilot program area chosen was two small lagoons called Minter Bay and Burley Lagoon. Both are classical lagoons partially enclosed by a sand spit formed by littoral accretion across their mouths. Burley Lagoon is 92 ha (230 acres) and Minter Bay is 32 ha (80 acres); both flush fairly well.

The watersheds, about 4,000 ha (10,000 acres) each, are characterized by rural residential uses. Small-scale farming for pleasure and supplemental income are common; commercial-scale agriculture is infrequent. The largest herd in Minter/Burley is a small dairy with 40 head. Residential and agricultural uses tend to be concentrated in the stream valleys with heavily forested hilly terrain higher up the watershed. Population in the two watersheds is about 10,000. A small commercial node exists next to Burley Lagoon. About 50 percent of the soils are poorly drained clays derived from glacial till.

The poor soils, rural residential use, and small-scale agriculture are typical of Puget Sound, although some areas do have more commercial farming.

A three-pronged approach addressed the nonpoint problem:

Water quality investigation. Using coastal zone management funds, the WDOE water quality investigation section conducted a year-long evaluation of water quality in the two estuaries to identify more clearly the sources of contamination and to provide a basis for developing and justifying a control program.

Farm management. The local conservation district was funded to begin a program of identifying farms with animal waste problems, to begin informational and educational programs, and to develop farm management plans.

Planning and land use. Planning grants were awarded to the two counties in which the watersheds occur to develop a pollution control program. A respected consulting firm was retained to prepare an evaluation of alternative strategies and ordinances that would institute appropriate controls.

These efforts were coordinated through a technical advisory committee, which had been previously established by Pierce County to develop ordinances to control the problem. After some initial tightening of the on-site waste disposal regulations, the committee had begun to lose momentum and focus. The use of this area as a pilot study was intended to strengthen the committee's performance of their original mission.

The results of this three-part program follow. Conclusions rather than methodology are emphasized for brevity.

WATER QUALITY SURVEY

The main features of the methodology were

1. bimonthly ambient sampling at 20 stations
2. two rain event samplings
3. correlation of bacterial loads, loads, and land uses along various reaches of the stream
4. special studies on time of travel, sediment, seepage, and seabird populations

The major conclusions from the extensive data collected were that all land uses throughout the entire watershed were contributing to the problem, in particular:

1. Stream segments with only agricultural use showed high loading.
2. Stream segments with only residential use showed high coliform loading.
3. Undeveloped control streams met the water quality standards.
4. Coliforms could easily survive in the fresh water for 3 days, long enough to reach the estuary from the farthest headwaters.
5. Shoreline residences could not account for the estuary loads.
6. In Burley Lagoon, correlation between estuarine conditions and stream loading was very high. In Minter Bay it was not as high. In Burley as little as 1/10 of an inch of rain could cause violations in estuarine water quality.
7. Sediments appeared in some areas to act as a reservoir of bacteria. Disturbance of sediments produced large increases in downstream counts. This was a possible factor in explaining lower correlations between stream loading and estuarine loads in Minter Bay.
8. No correlation at all developed between coliform levels and bird counts.
9. Rainfall events produced rapid increases of 6–10 times the typically observed loads during ambient sampling. Investigators concluded that we learned most from sampling while the system was rainfall-stressed and that future investigations should de-emphasize ambient sampling.

CONSERVATION DISTRICT PROJECT

The second part of the program inventoried and identified farm ownerships. About 30 farm management plans were developed. A handbook was developed describing agricultural best management practices (BMP's) that were most applicable to small farms. An unplanned, but significant, followup to this phase of the work came when WDOE secured a construction crew funded by a State jobs program that provided free (to the homeowner) labor for building improvements called for in the farm plans. Some 2,400 m (8,000 ft) of fences were built, plus a number of bridges and stock watering areas.

PLANNING PROGRAM

The local governments hired a respected consulting firm to evaluate alternative approaches to controlling the problem. Based on the WDOE water quality study, the consultants recommended concentrating on animal waste management practices, failing on-site waste systems, and erosion control. Since the area is quite rural, they recommended controlling these primary sources rather than addressing collected storm water. In one area of Puget Sound, urban storm water drains to a commercial shellfish culture area, and typically high bacteria counts (900/100 ml) have been found. Most shellfish cultures, however, occur in rural areas where infiltration is still high and the recommended approach is to keep densities low to avoid creating more serious stormwater problems.

The report recommended developing ordinances to control these three activities. The ordinance approach seemed necessary to ensure the long-run protection of the area. Only 20 to 30 percent of the watersheds were developed, so ignoring new development could quickly undo current corrections. The local governments had previously added political support by directing the staffs to develop ordinances to control the problems. This approach also suited the State interest in developing a program that was integrated into local land use controls. Because of the small scale nature of the farms, it has not been considered possible for direct state programs to effectively address the problem.

The recommended ordinances contained the following features:

Farm management. Each farm in the watershed would be required to have a farm management plan. The plan, to be prepared by conservation district or Soil Conservation Service (SCS) personnel, would conform to general policies, but considerable site-specific flexibility in the application of BMP's would be allowed. Farm plans were to be submitted to the Health Department as a condition of obtaining health or building permits.

On-Site Waste Management. This ordinance was modeled after a California county (Merced) ordinance. It required inspections of on-site systems periodically (2-year intervals were proposed), annual permits to help fund the system, and mandatory pumping if inspections failed.

Clearing and Grading. This ordinance set up a fairly standard permit system to authorize clearing and grading activities that result in excavation or fill in excess of a minimum amount. In Washington such permits are common in cities, but rare in counties.

The development of these ordinances has not been completed. While the technical committee was still engaged in developing a system for funding and implementing these programs, draft ordinances began to circulate in the local community. Opposition to the proposals grew very rapidly, culminating in a public meeting where 350 residents demanded a halt to the process.

Citizens expressed considerable resistance to a regulatory approach, to permit fees, and to various specific provisions of the draft proposals. There was refusal to admit a serious problem existed, demands to know the actual health risks, demands to let the oystermen go somewhere else, queries about depurating the oysters, and considerable finger pointing between farmers and residential users regarding who was most at fault. Despite a good data base, the political heat derailed the original proposals and resulted in a more lengthy and formal citizen advisory committee process being developed.

Although the ordinances were sidetracked, the results were not all negative. The controversy produced far higher awareness and interest than previous educational meetings. After the initial stormy meeting, large numbers of people began to show up at the conservation district office seeking farm plans. Cooler heads have generally been appointed to committees and a program will likely be developed that is less regulatory and more assistance oriented.

The general publicity and interest in Puget Sound water quality and shellfish contamination also spawned a number of good bills in the legislature. One of these, HB 1068 provided for a comprehensive approach for planning to control nonpoint pollution. The bill may not survive the dual problems of a State budget crunch and some local government resistance, but I would like to conclude this story with a brief description of it because it embodies the type of program that is needed to reverse the trend towards decertifications.

The bill required a cooperative State/local effort to address shellfish contamination. WDOE was directed to identify "closed correctable" and "highly threatened" commercial and recreational shellfish culture areas. WDOE was also to prepare minimum standards for land-use based nonpoint control programs. Local government was given a year to prepare local plans to control the sources of the pollution. The local plans would have to conform to the minimum State standards and would require WDOE approval before any implementation money would be released.

The bill provided funds for the planning and implementation for both State and local governments. Significantly, it also provided State funds for a farm assistance program parallel to the Agricultural Soil and Conservation Service program and funds for State Conservation Corps crews to construct such improvements. The cost for these programs in the estimated 20 watersheds was projected at $8 million.

This program was modeled to some extent after the State Coastal Zone Management Program operating through a similar mechanism of locally developed and administered but State approved programs. The bill addressed the critically important interrelationship between local land-use controls and nonpoint pollution and provided essential resources to develop and implement a program. Without such legislative support and direction for a serious nonpoint pollution control program, the shellfish problems in Washington will continue to worsen. Even with such a program, the task is formidable.

REFERENCES

Determan et al. 1984. Sources Affecting Bacteriological Conditions of Water and Shellfish From Minter Bay and Burley Lagoon. No. 84-10. Washington Dep. Ecology, Olympia.

Saunders, B. 1984. Shellfish Protection Strategy. No. 84-4. Washington Dep. Ecology, Olympia.

SHELLFISH SANITATION IN OREGON: CAN IT BE ACHIEVED THROUGH POLLUTION SOURCE MANAGEMENT?

JOHN E. JACKSON
Oregon Department of Environmental Quality
Portland, Oregon

ABSTRACT

Historically, shellfish growing areas are closed as man's activity pollutes the waters. As these areas close, businesses and jobs are lost in a local and State economy. Oregon is taking a different tack to maintain the limited growing areas available to private industry. Recently completed fecal waste source management plans in Tillamook Bay demonstrate that safe shellfish harvesting can exist in the same estuary as nonpoint and point source discharges—as long as who, what, and when they discharge is known. An overview is presented describing the process of pollution source identification, management option determinations, and management plan development and implementation.

INTRODUCTION

In recent years, much concern has been directed toward the water quality conditions of Oregon's estuaries and, in particular, those bays that receive pressure from commercial and recreational shellfish harvesters. Routine sampling and analysis of these bay waters, in some cases, show seasonally degraded water quality. In these bays, safe shellfish harvesting is precarious.

In the United States, when bays become contaminated by pollution, they are closed to further harvesting of shellfish. Closing a bay hurts the local and State economy. The commercial and recreational harvesters must go elsewhere for their shellfish, thus affecting the local economy. This is an unacceptable solution in Oregon.

In the bays threatened by closure due to pollution, Oregon is striving to accomplish a cleanup by achieving the stated goals of the Federal Water Pollution Control Act and the National Shellfish Sanitation Program (NSSP). A goal of the Federal Water Pollution Control Act states that ". . . wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983."

The NSSP goals are "(1) the continued safe use of this natural resource and (2) active encouragement of water quality programs which will preserve all possible coastal areas for this beneficial use." The natural resource referred to by the NSSP goals is shellfish: "Shellfish are a renewable, manageable natural resource of significant economical value to many coastal communities, and which should be managed as carefully as are other natural resources such as forests, water and agricultural lands."

In Oregon, shellfish propagation and harvesting come under the headings of "Resident Fish and Aquatic Life" and "Fishing" and are considered beneficial uses as stated in Oregon Administrative Rules 340-41-205 (Table 1). Oregon sets water quality standards to protect these nonprioritized beneficial uses of the water. One specific standard stated in OAR 340-41-205 is: "Bacterial pollution or other conditions deleterious to waters used for domestic purposes, livestock watering, irrigation, bathing, or shellfish propagation, or otherwise injurious to public health shall not be allowed."

The goals of the Clean Water Act and the National Shellfish Sanitation Program, coupled with Oregon's requirements to protect beneficial uses through abiding by water quality standards, provide that, if a water quality problem affects the shellfish resources, then action must be taken to correct the problem. In meeting the goals and correcting the pollution problem, Oregon is keeping bays open to shellfish harvesting, even when nonpoint and point source discharges exist in the water basin. This is accomplished by managing the pollution sources. The process is effective only when the sources, types, and frequency of pollution discharge are known.

Tillamook Bay and Coos Bay, two separate estuaries in Oregon, have been threatened by closures to shellfish harvesting in the past. This paper describes the process of pollution source identification, source management options and plan development, and, the 4 years of successful management in keeping these bays open for safe shellfish harvesting. For the sake of clarity, only the Tillamook

Table 1.—Recognized beneficial uses of Tillamook Bay and tributaries.

	Estuary and adjacent marine waters	Columbia River mouth to RM 86	All other streams and tributaries thereto
Public domestic water supply		X	X
Private domestic water supply		X	X
Industrial water supply	X	X	X
Irrigation		X	X
Livestock watering		X	X
Anadromous fish passage	X	X	X
Salmonid fish rearing	X	X	X
Salmonid fish spawning	X	X	X
Resident fish & aquatic life	X	X	X
Wildlife & hunting	X	X	X
Fishing	X	X	X
Boating	X	X	X
Water contact recreation	X	X	X
Aesthetic quality	X	X	X
Hydropower			
Commercial navigation & transportation	X	X	

Bay effort conducted by the Oregon Department of Environmental Quality (DEQ) will be discussed here.

THE TILLAMOOK BAY BACTERIA STUDY

In 1979, the Tillamook Bay Bacteria Study was initiated by the DEQ to specifically identify the sources and extent of fecal pollution occurring in the bay and its watershed. From the study, it was proposed that corrective actions would be developed to reduce the principal sources of fecal contamination to acceptable levels, so as to eliminate the potential health risk that occurs when a person accidentally ingests the water while swimming or eats the raw shellfish harvested from the bay.

The Tillamook Bay Bacteria Study consisted of five parts: (1) review of the existing data and information, (2) field investigations to fill gaps in knowledge, (3) definition of the problem and identification of the pollution sources, (4) development of a waste-management plan to address the sources and problem, and (5) adoption and implementation of the plan.

Throughout the study, the local citizens were kept informed of its progress. Not only was information disseminated to them, but the meetings, phone calls, and personal contacts made by the study team were instrumental in involving the public in the process. If the cleanup effort was to work, the local citizens had to make their concerns known, and these concerns had to be incorporated in the plan. Once the management plan was ready for implementation, the people knew what had to be done. Thus, implementation was made more effective and less controversial.

Tillamook Bay and Drainage Basin

The Tillamook Bay drainage basin is located on the northern Oregon coast in Tillamook County, approximately 77 km south of the Columbia River mouth and 96 km west of Portland. The watershed is 1,425 km^2. It is bounded on the east by the crest of the Coast Mountain Range and on the west by the Pacific Ocean. Five major river subbasins drain 97 percent of the total land area into Tillamook Bay.

Ninety percent of the basin is steep mountainous forested terrain. The forested lands are owned and managed separately by State, Federal, private, county, and municipal agencies in descending order of total ownership.

Eight percent of the land area is devoted to agriculture, primarily dairy farming. Located in this lowland area are 120 dairies. Total cow population is approximately 19,100 producing 256,360 tonnes of manure annually. The largest and smallest dairy herd number 400 and 60 cows, respectively. The average dairy holds 150 cows on 40.5 ha.

The population pattern is basically rural. People live primarily on the alluvial plain and terraces adjoining the bay. They are found in the towns of Tillamook, Bay City, Garibaldi, and the unincorporated area of Idaville. Very little shoreline development has occurred on the bay. However, many homes line the rivers and small tributaries inland. Total permanent population in the Tillamook Bay Basin for 1980 was 11,305. Recreational population having residences in the basin adds another 1,700 people to the total. Approximately 60 percent of the population is served by three separate sewage collection and treatment facilities. Two additional sewage treatment facilities serve the industrial areas of the Tillamook airport and the Tillamook Cheese Factory. All facilities discharge in the basin, with four discharging directly to the bay or tidal reaches of the rivers.

The area's climate is characterized by a strong marine influence, with 70 percent of its precipitation recorded during November through March. Winter storms often produce large amounts of precipitation over short periods of time, and cause sudden water-level changes in the rivers and occasional flooding of lowlands. The average annual rainfall is 229 cm along the coast and 381 cm inland to the north-central watershed.

Tillamook Bay covers an area of 36 km^2 at high tide and 18 km^2 at low tide, is 9.6 km long north to south, with a maximum width of 4.8 km, and acts as a catch basin for five rivers. The bay is shallow, averaging 1.8 m deep at high tide. At extreme low tide, the bay water is confined mostly to the narrow channels.

Shellfishing in Tillamook Bay includes recreational and commercial clamming, and commercial oyster harvesting. Clamming occurs throughout the bay. The commercially grown and harvested Pacific oyster is grown on approximately 11 km^2 of intertidal lands in the middle to upper bay, using ground-culture methods. Annual harvest approaches 600,000 clams and 79,546 kg of oysters.

The bay and tributaries also support a good fin fishery for salmonid fish species. When the fish are migrating, it is not uncommon to see 50–100 boats in the bay and hundreds of fishermen lining the rivers.

Because of the close proximity of the bay to the metropolitan area of Portland and the bay's location on the popular north Oregon coast, the area receives many tourists during holidays and the tourist season. The attractions are the aesthetic qualities, camping, biking, fishing, and the Tillamook Cheese Factory.

Review of Existing Data and Information

A review of past studies, current water quality information, and discussion with local citizens determined that the major problem in the bay was that high fecal coliform bacteria levels occur during rain events. This indicated that it was fecal contamination that threatened safe harvest of the bay's shellfish. The review also concluded that sources of the contamination had not been accurately identified. Possible sources included the sewage treatment plants, dairy wastes, and failing septic tanks.

One certainty in this phase of the bacteria study was that the people living in the cities thought that the dairies caused the pollution; the farmers thought the cause was the sewage treatment plants; and the tourists attributed the pollution to the seals in the bay or the elk herds and swimmers in the forested streams.

Field Investigations

Based on the review of existing data and information, the project collected additional water quality data from streams and from Tillamook Bay during differing weather conditions based on rain intensity, ground saturation conditions, and predicted fecal bacteria source discharges. Four different types of weather situations were selected: (1) heavy rain on saturated ground, (2) a rain after a period of dry weather, (3) a dry-weather, low river flow summer period, and (4) the first freshet storm of the water year.

Because of the lack of definitive information on the location of fecal source contributions and the confusion over the major contributors of the contamination, many fecal source types had to be considered. To ease the anxiety of the local citizens that they would be identified as a source, the fecal sources considered in this phase of the study were labeled "potential fecal sources."

Potential fecal source types considered in the sample design were dairy barnyards, dairy waste disposal methods on pastures, failing (or lack of) septic tanks, sewage treatment plants, elk herds, heavy outdoor recreational use areas, forestry activities, and seals.

Sample site selection was based on: (1) paired watersheds; (2) changes in land use; (3) a small watershed

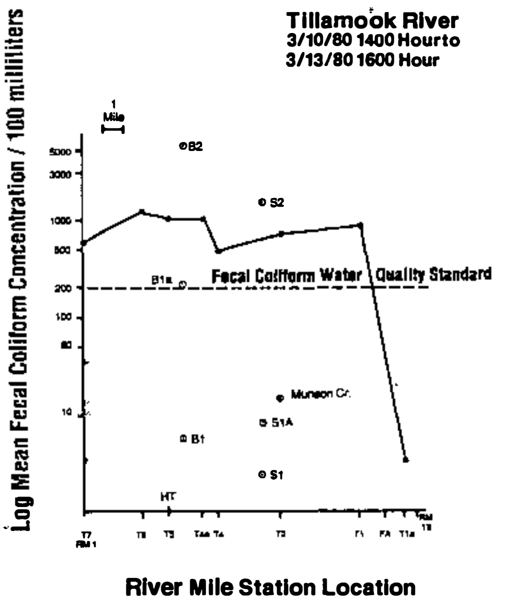

Figure 1.—Tillamook River and tributary fecal coliform concentrations by river mile. RM = River Mile; FA = Forest-Agriculture common boundary.

having only one or two land uses, such as forestry, forestry-agriculture, or forestry-urban; (4) previous sample stations; (5) potential fecal source locations; and (6) location of shellfish growing areas. Seventy-one tributary sites and 14 bay sites were sampled during each storm. Tributaries were sampled every 8 hours, the bay was sampled during daylight, high and low tides, and oysters during the low tides.

The water and oyster meat samples were analyzed for total and fecal coliform bacteria. Some selected sites were also sampled for fecal streptococcus to be used in the fecal coliform/streptococcus ratio determinations. All analyses used approved standard methods.

The analyses of the data consisted of comparing each station's data for each storm event against the established bacteria standard for that type of water. A plot of log mean fecal concentration versus river mile (Fig. 1) and a plot of fecal bacteria concentration (organisms/100 mL) versus time (Fig. 2) were made for each storm and for each sample station.

Fecal bacteria loading of the bay was determined by calculating the area under the curve for bacteria concentration and river discharges. Bay loadings were also calculated using bacteria median values obtained for the sample period at the farthest downstream sample site in each major river basin.

Sources contaminating the tributaries and bay under a given weather condition were identified based on similar watershed comparisons, the land use immediately surrounding and upstream of each sample site, the magnitude of fecal bacteria contributions, and the response characteristics of each bacteria source type.

To determine the relative impact of each source type on the shellfish meat bacteria quality, it was necessary to know the travel speed and circulation pattern of the freshwater in the bay. A rhodamine B dye dispersion study of freshwater entering the upper end of Tillamook Bay was done by U.S. Food and Drug Administration (FDA), DEQ, and Oregon State Health Division staff.

Bay circulation patterns were also photographed. The Oregon National Guard provided thermal infrared photographs taken approximately 1 hour before an evening low tide. Contact prints were produced from the film and

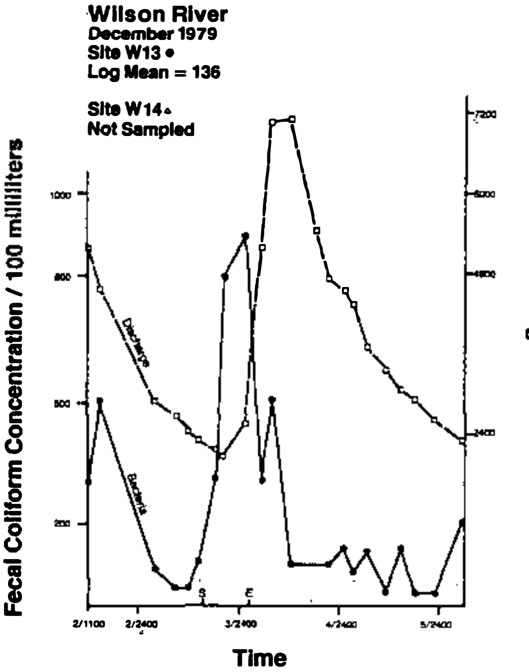

Figure 2.—Comparison of Wilson River fecal coliform concentrations and river flows over time. S = Start of storm; E = End of storm.

pieced together to make a mosaic of the bay. These photos and the FDA work were compared and used to determine the flow pattern of the freshwaters entering the bay.

Pollution Source Identification and Water-Quality Impacts

Because of the complex interaction of fecal source types and the five major watersheds discharging into the bay, the results of the water sampling and analyses were displayed in two ways: (1) the impacts of each watershed, its loading of the bay and the circulation of freshwater in the bay from each watershed; and (2) the impacts of each fecal source type (dairy waste, septic tanks, etc.) on the watershed into which it drains.

Conclusions from the data for the rivers and bay indicated that a potential mechanism for waterborne disease transmittal by shellfish from animals to man and man to man exists in the Tillamook Bay Drainage Basin and Tillamook Bay.

Furthermore, bacterial quality of Tillamook Bay as measured by fecal coliform levels is more degraded shortly after heavy rains begin. During the winter months, these rains usually produce turbidity, low salinities, and low temperatures in the bay waters, thus creating suboptimal feeding conditions for the oysters which, in turn, reduce the potential of harvesting contaminated oysters. During the summer rains, the optimum feeding conditions persist but with a lesser degree of bacterial degradation to water quality. The data suggest, but with minimal confidence (more oyster meat samples are needed), that the summer rains may produce fecal bacteria conditions in the bay water more critical for safe shellfish harvesting than rains during the winter months.

It was found that most of the fecal coliform bacteria recovered in the bay originated from dairy animal and human fecal sources in the river subbasins. The waters from the Wilson, Trask, and Tillamook Rivers flow over the oyster beds in the bay on the ebb tide. Waters from the

Miami and possibly the Kilchis River reach the same beds on a flood tide, but are somewhat diluted by fresh seawater. The clam beds located throughout the bay have water from one or more rivers flowing over them during parts of each tidal cycle.

Finally, small streams in the near bay area also carry fecal bacteria, but because of their small discharges relative to the large rivers, they have negligible impact on the bay.

Conclusions from the data for each fecal source type indicated that:

- Sewage treatment plants have the potential, when they malfunction, for contaminating the surface waters of the bay drainage basin, in addition to directly contaminating the bay. None malfunctioned during the study.
- Dairy operations, primarily manure storage and disposal in the barnyards and on the pastures, are contaminating the surface waters of the drainage basin with manure runoff when it rains, or the manure is inadvertently applied directly to ditches and streams when being spread on the pastures.
- Inadequate on-site subsurface sewage disposal systems is also contaminating surface waters of the drainage basin when it rains, or the lack of such systems is contaminating the streams regardless of weather conditions.
- Other fecal sources, such as wild animals, recreation, forestry activities, and industry, are not significant contributors to the fecal contamination of Tillamook Bay and its drainage basin. It is recognized that a local impact to the environment could occur near one of these sources if it should discharge fecal bacteria.

What was known at this point in the study was: (1) how the bay and rivers interacted hydraulically; (2) who, how, and when the fecal sources contaminated the surface waters; and (3) under what weather and runoff conditions the shellfish in the bay become contaminated. This knowledge formed the basis for developing management options to control the pollution problems identified.

Development of the Fecal Wastes Management Plan

Throughout the study, local citizens were actively involved. A group of interested citizens met regularly to review the data collected and analyzed by the DEQ. They experienced the same accomplishments, defeats, and frustrations as the study team when arriving at the conclusions from the data. These same citizens developed the management options to control the problem. At this point, because of their involvement in the data-analysis phase, the people were better equipped to suggest solutions to the problems. The DEQ's role in this effort was to ensure that the management options addressed the problems. Dairymen developed the solutions to the dairy problems. County sanitarians developed control strategies for the septic tank problems. Sewage treatment plant owners and operators developed the strategy for minimizing impacts from their plants.

Management options that were considered in addressing the pollution problem were: (1) closing the bay to harvesting of shellfish allowing status quo correction of the pollution problems from the fecal sources; (2) initiating new types of corrective actions aimed at reducing the pollution potential of the identified fecal sources and developing closing-opening criteria for the bay; (3) strengthening of existing programs responsible for the fecal source types identified and developing closing-opening criteria for the bay.

The local people wanted an effective plan that would avoid extensive implementation costs. They knew that the plan had to reduce the pollution potential in the most economical manner feasible.

The last option (strengthening of existing programs and developing closing-opening criteria) was chosen, primarily because no new programs had to be instituted for the sewage treatment plant and subsurface sewage disposal systems. In agriculture, the industry had made the decision to develop a pollution abatement plan in Tillamook County. Local citizens did not want to duplicate agency efforts, but they did want to find a way to make existing programs more effective, particularly since the mechanisms, effective or not, for correcting the pollution problems were already in place and operating. To accomplish this, no additional funds or personnel were needed.

Developing a bay closing-opening criteria, along with strengthened source control programs, was deemed necessary to ensure safe shellfish harvesting in the interim while the fecal sources were being corrected. Application of the closing-opening criteria did not hurt the shellfish industry, because the industry already had self-imposed, limited harvesting during critical runoff periods.

The Tillamook Bay Drainage Basin Fecal Wastes Management Plan is divided into three parts. Each part addresses a fecal source type, its location, and timing of discharge from that source. Each part is independent of the other parts in strategy and implementation schedules. The whole plan recognizes the legal responsibilities of each fecal source to eliminate their discharge, but accomplishes the cleanup in such a way that it does not force permanent closure of an activity.

For the problem of malfunctioning sewage treatment plants, a malfunction notification procedure was developed. This required that additional alarm and shutdown equipment be installed in the plants and collection systems. It also required plant personnel to notify health and environmental officials immediately in the case of a malfunction.

For the on-site subsurface sewage disposal problems, the plan identified critical problem areas and assigned priorities for correction. This document is used by the county to prioritize work and for budget preparation.

Dairy waste was found to be the most pervasive problem in the basin and a continuous source of fecal material to the bay. Since this was the case, the local agricultural community, with financial assistance from Section 208 funds from the U.S. Environmental Protection Agency, developed an extensive plan for the basin. The Tillamook Bay Drainage Basin Agricultural Nonpoint Source Pollution Abatement Plan cleanup strategy simply stated is: (1) Keep clean rainwater and surface waters from coming into contact with manure and if that is not possible; (2) prevent the contaminated water from entering streams, rivers and ditches by intercepting, storing and disposing of the manure contaminated water in a sanitary manner.

The plan developed from this strategy directs each farmer to develop individual farm water quality plans. Each plan addresses the water quality problems of that farm and displays a 3–15 year schedule for implementation of best management practices specifically designed for the farm, so that the practices fit the established farm management scheme.

Since we recognize the long-term nature of the cleanup and the need for immediate action to safeguard public health, tradeoffs between management of fecal sources and harvesting of shellfish had to occur immediately. To this end, a bay closing and opening procedure was adopted, based on criteria developed from the study of the interaction of fecal sources, river to bay hydraulics, and oyster meat bacterial quality.

The procedure dictates temporary bay closures for sewage treatment malfunctions, for first and second major rainfall events in the fall, for winter storms that cause rapid increases in river flows and the resultant possible flooding, and for summer storms that cause moderate levels but a rapid rise in river flows.

Fecal Wastes Management Plan Implementation

The plan and bay closure criteria were adopted by local and State agencies and organizations in July 1981. Today, the spring of 1985, implementation of the Plan continues to be successful. This success can be attributed to at least two factors: (1) the involvement of local citizens throughout all phases of the study fostered local pride in the accomplishments and, more important, fostered a pride in the livability of the Tillamook area; and (2) funding to accomplish the implementation of the plan. Whether it is appropriate to recognize the fact, money still solves problems. A change in public attitude toward a problem can accomplish a lot, but in many cases, money is needed to effect such a change in attitude. For example, on a farm, the attitude change that manure is an asset to be applied to pastures as fertilizer rather than a liability to be piled next to the creek and washed away, accomplishes a lot toward achieving a cleanup. Yet without storage areas in the barnyard away from the rain, the farmer has transferred the problem away from the stream and has placed the problem where a ditch now transports the accumulating rainwater and manure to the stream. It takes longer to get to the bay this way, but the problem has not been solved without roofed or curbed storage areas.

What has been accomplished to date? The sewage treatment facilities now have alarms and shutdown devices that operate when critical equipment malfunctions. Each plant has, as a part of its discharge permit, the requirement to initiate the malfunction notification procedure.

The problem areas for septic tanks are still under investigation, with corrective measures being instituted. One severe problem area previously identified has now had sewers installed.

As for the 120 dairies, the Tillamook Soil and Water Conservation District has received more than $3 million to assist dairy owners in cleaning up priority problem dairy farms. The farmers have also committed more than $1.8 million of their own resources to the cleanup effort. This work is being carried out on over 70 farms.

What is happening to the water quality trends in the rivers and bay with all this activity on the land? Preliminary indications are that an improving trend in bacterial water quality is occurring in the rivers. An unequivocal statement of water quality trend cannot be made at this time, however.

SUMMARY

Can shellfish sanitation be achieved in Oregon through pollution source management? Yes. Tillamook Bay, discussed in this paper, and Coos Bay, mentioned here but not discussed, are both important estuaries for the shellfish and recreational industries in Oregon. Neither has been closed permanently to shellfishing even though both receive wastes from other industries and at one time had poor shellfish sanitation characteristics. With regard to Tillamook, industries and dairy farming are still open for business. People still live in the watersheds to the bay, and they still flush their toilets. What has changed to improve the water quality situation?

The most important factor is that people's attitudes toward how they live have changed. People now realize that how they handle wastes in their homes and businesses will have an effect on some other person's business, livelihood, and recreation.

Along with this attitude change have come tools to help people prevent and control water pollution. A new area of the city of Tillamook has been sewered. There is a red light in a police station to alert someone that the sewage treatment plant is not working in the middle of the night. Concrete tanks now store manure and curbs around the dairy barnyards control manure runoff, where once bare, sloping ground was covered with piles of manure in the rain.

With knowledge of who, how, and when sources of pollution operate and discharge in a watershed and bay, point and nonpoint source discharges can coexist with the shellfish industry. This can occur to the point that no industry or person is hurt—least of all the public that loves shellfish.